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ASD TECHNICAL REPORT 61-147

AD. 270453

NORMAL SPECTRAL REFLECTANCE OF ANODIZED COATINGS ON ALUMINUM, MAGNESIUM, TITANIUM AND BERYLLIUM

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HONEYWELL RESEARCH CENTER
HOPKINS, MINNESOTA

SEPTEMBER 1961

AERONAUTICAL SYSTEMS DIVISION

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DIRECTORATE OF MATERIALS AND PROCESSES
CONTRACT No. AF 33(616)-6191
PROJECT No. 7312

AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

700 - January 1962 - 16-687 & 688

FOREWORD

The report was prepared by the Honeywell Research Center under USAF Contract No. AF 33(616)-6191. The contract was initiated under Project No. 7312, "Finishes and Materials Preservation", Task No. 73120, "Surface Treatments and Coating". The work was administered under the direction of the Directorate of Materials and Processes, Deputy for Technology, Aeronautical Systems Division. The work was initiated with Mr. Bennie Cohen acting as project engineer, and was continued under supplemental agreement No. S1 (60-1001) to the completion of the project with Lt. N. M. Geyer as project engineer.

This report covers work conducted from January 1959 to May 1961. Eleven bi-monthly progress reports (1) were written during the course of the investigation under the title, "Measurement of Spectral Reflectance of Anodized Metals". The title of this final report has been changed to make it more descriptive.

The authors wish to acknowledge the contributions of K. E. Nelson of the Solar Radiation Laboratory of the University of California, Los Angeles Branch, and C. C. Shaw of Lockheed Missiles and Space Division, Lockheed Aircraft Co., Sunnyvale, California. Their reflectance measurements on several specimens prepared for this investigation provided a valuable comparison. The contributions of C. H. Jackson and R. L. Sampson of the Honeywell Research Center during the early phase of this study were also important.

ABSTRACT

Selection of materials having proper thermal radiation properties permits the engineer to achieve passive temperature control in spacecraft. The object of this investigation was to study the effect of various variables in the anodizing process on the reflectance of anodized metals. The integrating hemisphere was modified by adding a diffuser and then locating the sensor external to the hemisphere so that measurements could be made over the range of 0.4 to 22 microns in vacuum with specimen temperatures from 100 to 1300 F. Methods for extending both the spectral and temperature ranges are discussed.

Normal spectral reflectance data on 158 specimens of anodized aluminum, magnesium, titanium, and beryllium are presented. Aluminum anodized in sulfuric acid gave a ratio of solar absorptance to infrared emittance of about 0.3 while A110AT titanium anodized in sodium hydroxide gave a value of $\alpha/\epsilon = 7$. In general, the anodizing process had a greater effect on the reflectance than did alloying elements in the metal. Measurements at elevated temperatures indicated a loss of water from coatings that contained water. In general, it was the presence of this water which produced high emittance in the infrared region and gave low values for α/ϵ, however.

Publication Review

This report has been reviewed and is approved.

FOR THE COMMANDER:

I. Perlmutter

I. PERLMUTTER
Chief, Physical Metallurgy Branch
Metals and Ceramics Laboratory
Directorate of Materials & Processes

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PART I

INTRODUCTION

Means for passive temperature control are of primary importance in the successful operation of satellites and space vehicles. Since there is no atmosphere in space, heat transfer to and from an object occurs only by radiation. Solar energy incident on the surface is either absorbed or reflected, and internal heat from the vehicle is dissipated as infrared radiation. Solar energy is concentrated in the short-wavelength region of the spectrum -- 90% occurs at wavelengths shorter than 1.6 microns, whereas low-temperature radiation from a satellite or space vehicle is confined to the long-wave infrared region. Variations in the spectral radiation properties of the surface of such vehicles can, therefore, be used to achieve passive temperature control.

Bare metals are good reflectors for both short- and long-wavelength radiation. They are relatively poorer reflectors for solar energy, however, and therefore attain undesirably high equilibrium temperatures in space. Materials such as white paint have more desirable thermal radiation properties but are frequently unstable in the high vacuum of interplanetary space. Paint pigments also tend to be unstable in the intense ultraviolet radiation from the sun.

Anodized coatings on metals have many desirable physical properties, and the object of this investigation was to study the effect of the various variables in the anodizing processes and a vacuum environment on the thermal radiation properties of several anodized metals. The spectral reflectance of aluminum, magnesium, titanium, and beryllium anodized by a number of different processes was measured over the range of 0.4 to about 22 microns. Measurements were made on two different alloys of each metal in a vacuum of about 10^{-6} mm of Hg with specimen temperatures up to 825F for aluminum, 350F for magnesium, 1300F for titanium, and 1200F for beryllium.

Manuscript released by authors June 1961 for publication as an ASD Technical Report.

Reflectance measurements were chosen because there would be insufficient energy for emittance measurements in the case of most of the specimen temperatures to cover the desired spectral range. The requirements of variable specimen temperature and high-vacuum eliminated many of the measurement techniques commonly used. A Gier-Dunkle, black-body reflectometer especially designed for vacuum operation was originally proposed and tried. Serious evaporation and outgassing problems made it impossible to use this device, however. A modified Coblentz integrating hemisphere was then conceived and was successfully used.

DISCUSSION

Four properties of materials are important in radiation calculations. These are emissivity (ϵ), absorptivity (α), reflectivity (ρ) and transmissivity (τ). An energy balance for the case of radiation incident upon a surface shows that the radiation is either absorbed, reflected, or transmitted. Therefore

$$\alpha + \rho + \tau = 1 \tag{1}$$

Most solid materials--and metals especially--are opaque to thermal radiation ($\tau = 0$) and

$$\alpha + \rho = 1 \tag{2}$$

Equations (1) and (2) are true for either the total radiation integrated over the entire spectrum or the spectral radiation at any particular wavelength.

$$\alpha_\lambda + \rho_\lambda = 1 \tag{3}$$

Kirchhoff's law states that for a surface at a given temperature

$$\alpha_\lambda = \epsilon_\lambda \tag{4}$$

Equations (3) and (4) show that if any one property can be measured, the others can be calculated.

The temperature range of interest extends down to 100 F and the wavelength range extends down to 0.4 microns. The amount of energy radiated by a surface at 100 F in the 0.4 micron region is infinitesimal and it would be difficult if not impossible to measure the emissivity directly under these conditions.

Energy of any desired intensity (provided it does not heat the surface unduly) can be projected onto a surface for reflectance measurements, however. For these reasons spectral reflectance was chosen as the property to measure

BLACK-BODY REFLECTOMETER

The original proposal was to use a black-body reflectometer of the type developed by Gier, Dunkle, and Bevans (2) for reflectance measurements. This device consists of a heated hohlraum (black-body enclosure) in which the specimen is mounted on a cooled mount as shown in Figure 1. A viewing aperture is located in the wall opposite the specimen. The hot walls of the hohlraum radiate to the specimen and some of this energy is reflected out the aperture to a sensor. One measurement is made of the energy reflected by the specimen and a reference measurement is made of the energy radiated from another part of the hohlraum. The reflectance is then equal to the ratio of the signals. If the specimen temperature approaches the hohlraum temperature, a correction for the energy emitted by the specimen is also required. A derivation of the equations and detailed discussion of this device is given in the appendix.

A ceramic hohlraum and vacuum chamber were built and measurements were attempted. In order to have sufficient energy for measurements at the short- and long-wavelength ends of the spectrum, it was estimated that the hohlraum would have to operate at about 2000 F. Specimen temperatures were to be varied from 100 to 1000 F. A serious evaporation problem was encountered at a hohlraum temperature of about 1200 F and a vacuum of 10^{-4} mm of Hg, however. Under these conditions, material that evaporated from the hot parts condensed on the relatively cold (100-200 F) specimen and specimen holder. A black residue was scraped from the specimen and holder and was analyzed by x-ray and infrared spectrographic methods. It was found to be predominantly lead molybdate ($Pb \cdot MoO_4$). The molybdenum obviously came from the molybdenum radiation shield which showed evidence of oxidation. The only source of lead in the system was soft solder used to seal the heater leads into the tubular hermetic seals. It was expected that some oxygen and nitrogen would be liberated from the ceramic parts during the warmup. Since these gases are transparent in the wavelengths region of interest, it was not expected that they would interfere with the measurements. Materials with vapor pressures well below the chamber

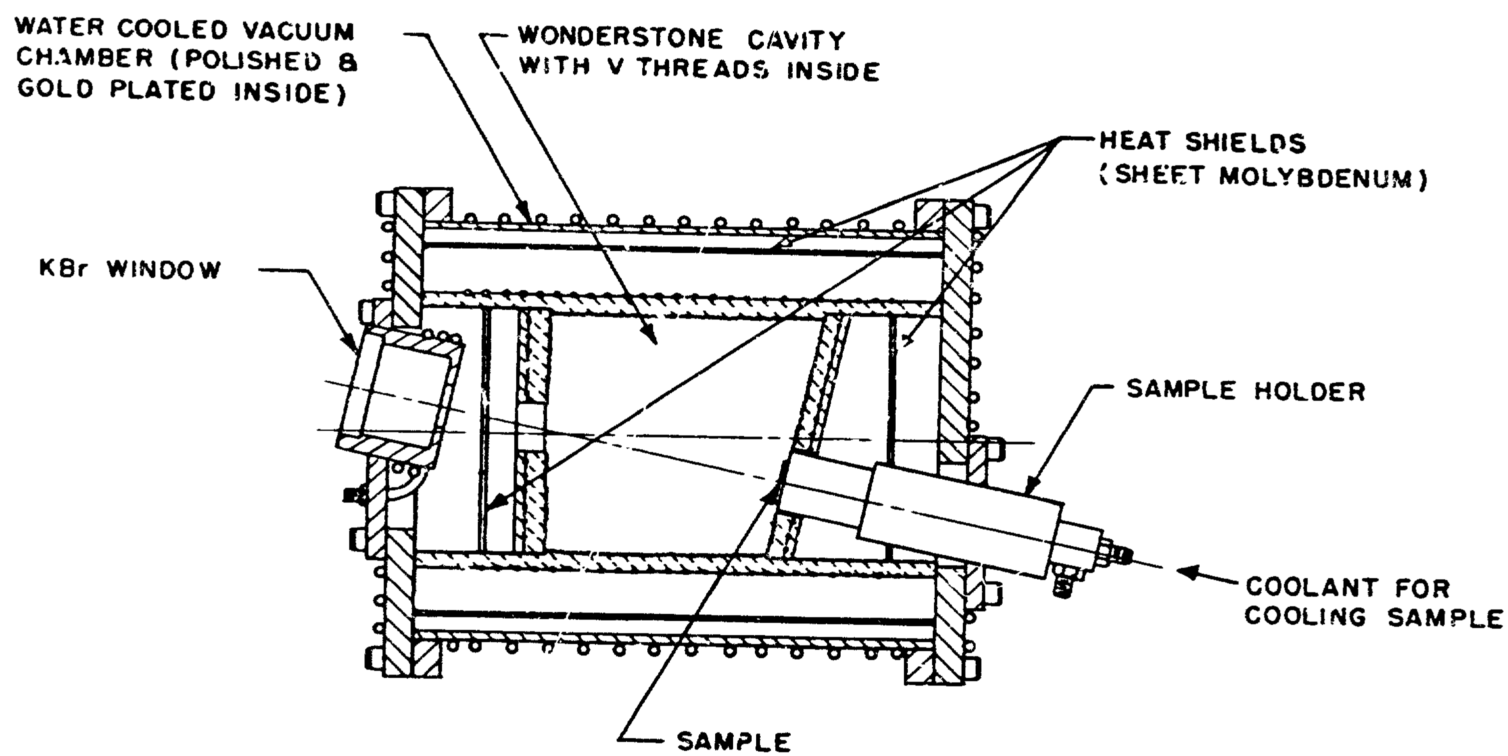


Figure 1 - BLACK BODY REFLECTOMETER

pressures, were selected for the hot parts. Apparently, however, the oxygen liberated from the hot ceramic attacked the molybdenum radiation shield and formed intermediate oxides with a relatively high vapor pressure which then evaporated at higher temperatures. Also it appeared that sufficient heat was conducted down the power leads to evaporate lead from the soft solder at the seals. This lead and molybdenum oxide vapor then must have combined and condensed on the specimen which was the coolest surface in the hohlraum.

This condensation on the specimen aggravated a second problem. The specimen in the form of a 1-1/8" diam. disk was clamped to the end of a water cooled mount by a ring around its edge. As the hohlraum temperature increased, the increasing heat flow through the specimen to the mount raised the specimen temperature slightly which produced sufficient thermal expansion to cause the specimen to "oil can" and separate from the specimen holder. Once this happened, the specimen cooling mechanism was virtually destroyed and the specimen temperature rapidly rose to the melting point.

Because of the very fundamental nature of these problems, it appeared advisable to conclude that the black-body reflectometer was not suitable for vacuum measurements and to abandon that technique. A modified version of the integrating hemisphere used by Coblentz was then conceived and used for the study.

INTEGRATING HEMISPHERE REFLECTOMETER

The earliest use of a highly specular reflecting hemisphere to collect the scattered energy reflected by a diffuse surface and concentrate the energy on a sensor is attributed to Paschen in 1899 (3). Coblentz published considerable data obtained with a similar instrument about 10 years later. In these devices a hollow, highly polished, glass hemisphere with a highly reflective evaporated metal coating was used to approximate an elipsoidal mirror. A specimen was located a short distance to one side of the center of the hemisphere and a thermopile was located at a conjugate position. Radiant energy from a suitable

source was projected through an aperture in the hemisphere onto the specimen. The reflected energy was collected by the hemisphere and focused on the thermopile. A reference measurement was made by projecting the same energy directly onto the thermopile. The reflectance of the specimen was then equal to the ratio of the two measurements divided by the reflectance of the hemisphere.

In order to adapt this technique to spectral measurements and heated specimens, it was necessary to introduce a diffuser at one of the conjugate foci and use an external optical system to focus the energy into a spectrometer. The wide spectral range of interest and the low energy levels, required the use of a photo multiplier sensor for the visible region and a vacuum thermocouple for the infrared.

Theory

Figure 2 shows a schematic of the integrating hemisphere. A diffuse reflector (diffuser) was located on a diameter of the hemisphere a short distance to one side of the center and the specimen was located at a conjugate position. The hemisphere was large enough compared to the distance between the diffuser and specimen so that it approximated an elipsoid.

The energy from a tungsten lamp or globar was projected through an aperture and focused on the diffuser. The energy reflected from the diffuser was re-collected by the hemisphere and focused onto the specimen. The diffuser reflected with a good approximation to Lambert's cosine law, thus irradiating the specimen with a hemispherical distribution of incident energy. Some of the energy was reflected out the exit aperture and some was re-reflected back to the diffuse reflector. An infinite number of internal reflections between the diffuser and specimen occurred with some energy being reflected out the exit aperture to the spectrometer with each internal reflection.

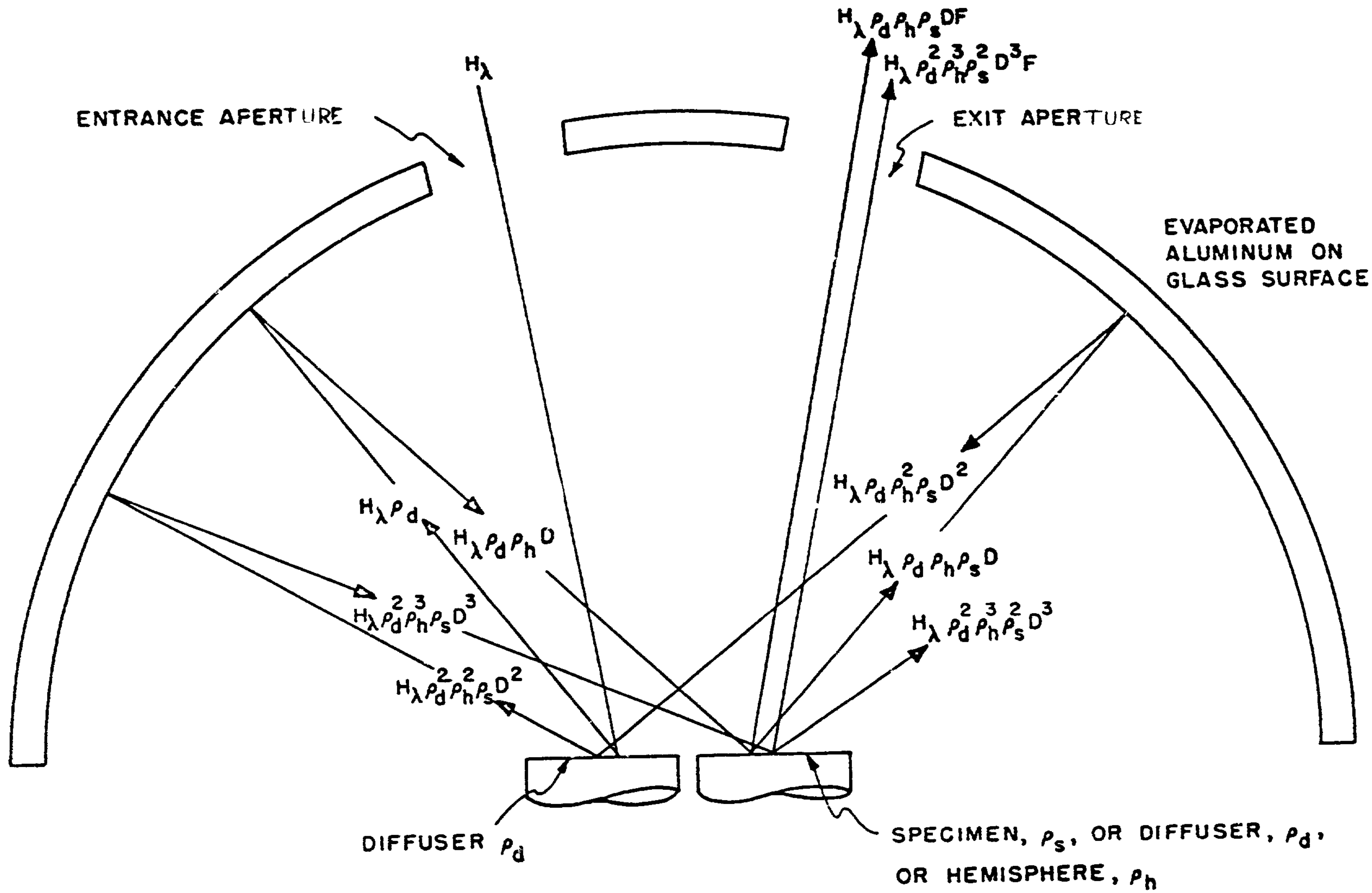


Figure 2 - ENERGY REFLECTION IN INTEGRATING HEMISPHERE

The equation for the energy reaching the sensor was derived by following a ray of energy through the system as shown in Figure 2. The summation of the energy reaching the sensor was a geometric series as follows:

$$G_{ds} = H_\lambda \rho_d \rho_h \rho_s \; D \; F \left[1 + \rho_d \rho_h^2 \; \rho_s \; D^2 + \rho_d^2 \; \rho_h^4 \rho_s^2 \; D^4 + \cdots \right] \quad (5)$$

G_{ds} = energy at sensor for diffuser and specimen at wavelength λ *

H_λ = incident energy at wavelength λ

ρ_d = diffuser reflectance at wavelength λ

ρ_h = hemisphere reflectance at wavelength λ

ρ_s = specimen reflectance at wavelength λ

D = factor to account for energy lost out apertures = $1 - F_i - F_e$ (see calculation page 24)

F_i = solid angle between diffuser or specimen and inlet aperture

F_e = solid angle between diffuser or specimen and exit aperture

F = solid angle factor between specimen and sensor

The sum of a finite number of terms in a geometric series is given by

$$S = a \frac{1 - r^{n+1}}{1 - r} \quad (6)$$

The sum of the series for a finite number of internal reflections was therefore:

$$G_{ds} = \rho_s \rho_d \rho_h \; H_\lambda \; DF \; \frac{\left[1 - (\rho_s \; \rho_d \; \rho_h^2 \; D^2)^{n+1}\right]}{\left[1 - \rho_s \rho_d \; \rho_h^2 \; D^2\right]} \quad (7)$$

---

* Throughout this report energies and reflectances are spectral values at wavelength λ. Subscript, λ, has been omitted to simplify notation.

A similar equation was written for the case of two diffusers:

$$G_{dd} = \rho_d^2 \rho_h H_\lambda DF \frac{\left[1 - (\rho_d^2 \rho_h^2 D^2)^{n+1}\right]}{\left[1 - \rho_d^2 \rho_h^2 D^2\right]} \tag{8}$$

Also, if one of the diffusers was replaced by a surface identical to the hemisphere surface (h), the energy reaching the sensor was given by:

$$G_{dh} = \rho_d \rho_h^2 H_\lambda F \frac{\left[1 - (\rho_d \rho_h^3 D^2)^{n+1}\right]}{\left[1 - \rho_d \rho_h^3 D^2\right]} \tag{9}$$

The loss factor, D, does not appear in the first term of the series from which equation (9) is derived when the specimen or second surface is highly specular. The reason for this is that the energy reflected by the specular surface to the sensor comes from a particular, small area on the hemisphere and the energy lost out the apertures after reflecting from the diffuser does not effect the energy incident on this spot. When the energy is reflected back to the diffuser for the second pass, this loss is integrated by the diffuser and must be included, however.

From the ratio of the signals G_{ds} and G_{dd}:

$$\frac{G_{ds}}{G_{dd}} = R_{sd} \frac{\left[1 - Z_d\right]\left[1 - (R_{sd} Z_d)^{n+1}\right]}{\left[1 - R_{sd} Z_d\right]\left[1 - Z_d^{n+1}\right]} \tag{10}$$

where $$R_{sd} = \frac{\rho_s}{\rho_d} \tag{11}$$

$$Z_d = \rho_d^2 \rho_h^2 D^2 \tag{12}$$

The specimen reflectance ρ_s could then be determined if ρ_d, ρ_h, and n were known. The loss factor, D, is calculated later. Also from the signals G_{ds} and G_{dh} a second equation for specimen reflectance was obtained.

$$\frac{G_{ds}}{G_{dh}} = R_{sh} \; D \; \frac{\left[1 - (R_{sh} \; Z_h)^{n+1}\right] \left[1 - Z_h\right]}{\left[1 - R_{sh} \; Z_h\right] \left[1 - Z_h^{\;n+1}\right]} \tag{13}$$

$$\text{where } R_{sh} = \frac{\rho_s}{\rho_h} \tag{14}$$

$$Z_h = \rho_d \, \rho_h^{\;3} \; D^2 \tag{15}$$

The procedures used in determining ρ_d, ρ_h, and n are covered in the section on calibration.

Description of Apparatus

The integrating hemisphere reflectometer along with its optical system and vacuum chamber were designed for use with the Perkin-Elmer Model 112 infrared spectrometer. The spectrometer and special image rotating mirror on the entrance are shown in Figure 3.

A war surplus mbsight bubble was used as the hemisphere. It was actually slightly more than a hemisphere and had a steel mounting flange attached. The hemisphere was glass, precision ground and polished to approximately 9-3/8" inside diameter. Two 1" diameter holes were drilled in the hemisphere for the entrance and exit apertures and the inside was aluminized by vacuum depositing an opaque coating of high-purity aluminum.

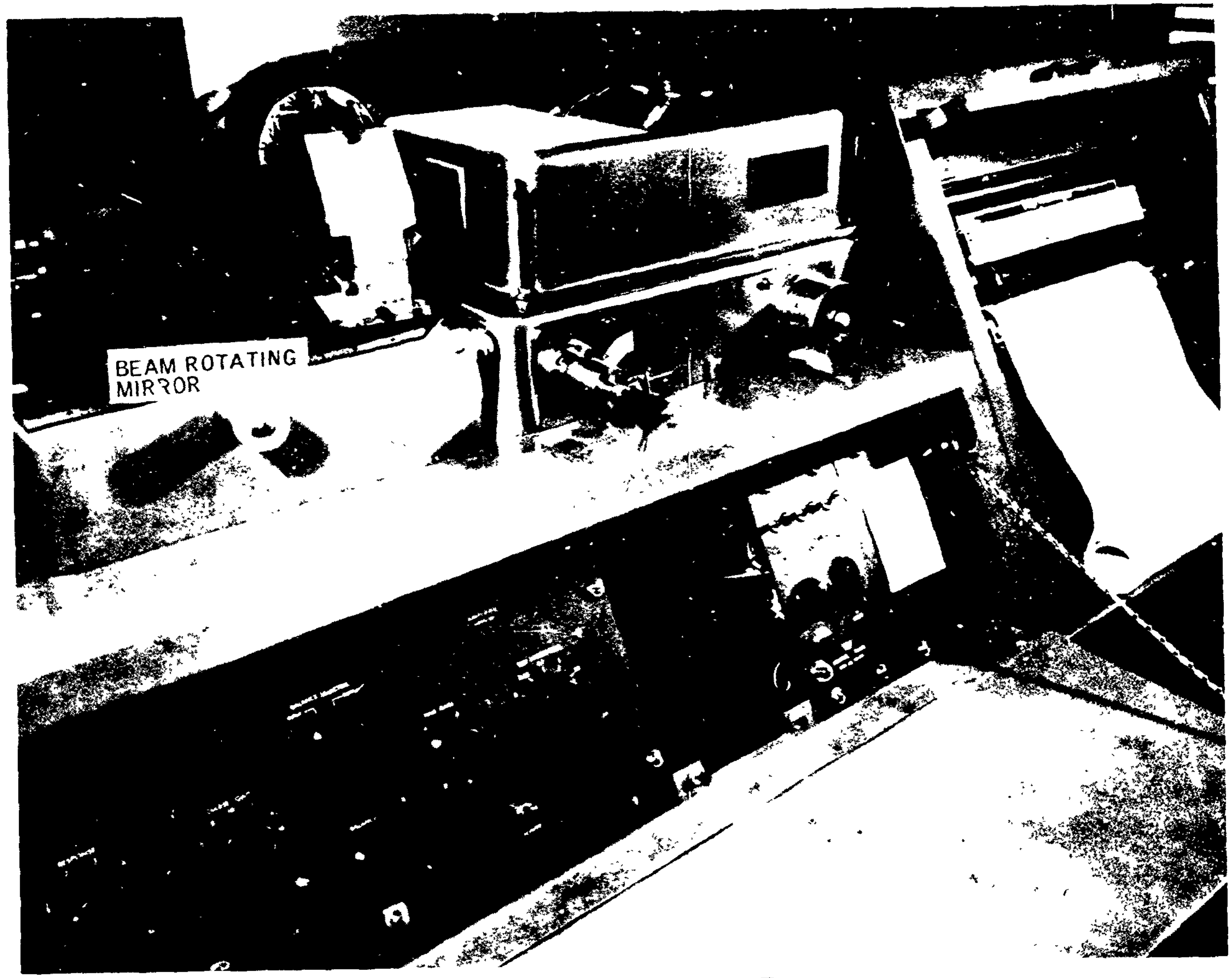


Figure 3 - SPECTROMETER

A turret with eight positions was provided for mounting specimens and the various diffusers and reference surfaces at the proper location with respect to the center of the hemisphere. Ceramic specimen holders with tungsten heating elements were provided for mounting specimens at two positions and a chromel-alumel thermocouple welded to a small flat nickel strip was held to each specimen surface with a spring-loaded clip made of tungsten wire. Specimen temperatures were recorded with a Brown recorder. Figure 4 shows the hemisphere, and turret with the various diffusers, specimen heaters and a specimen. The heaters were powered by storage batteries and a rheostat was used for control purposes. Water cooling was provided to keep the diffusers at approximately room temperature.

Optical alignment of the diffuser and specimen with respect to the integrating hemisphere was quite critical. An external nut on the turret tube and means for positive indexing were, therefore, provided to adjust the location of the specimen and diffuser surfaces with respect to the center of the hemisphere. The height of the individual surfaces on the turret could also be independently adjusted to bring any two or more to the same height and thus make allowance for variation of specimen thickness.

The hemisphere was mounted on the rear end plate of the vacuum chamber and the turret was mounted on a second plate bolted to the rear end plate as shown in Figure 5. This arrangement made it possible to remove the turret to change specimens without disturbing the hemisphere. A rotary seal consisting of two O-rings lubricated with diffusion pump oil was provided for turret rotation. Two 3-inch diam. potassium bromide windows were provided in the front end plate and a heater was provided to keep these windows at a temperature of about 100 F to prevent fogging. The vacuum gage was also mounted in the front end plate. Neoprene O-ring gaskets were used at all joints.

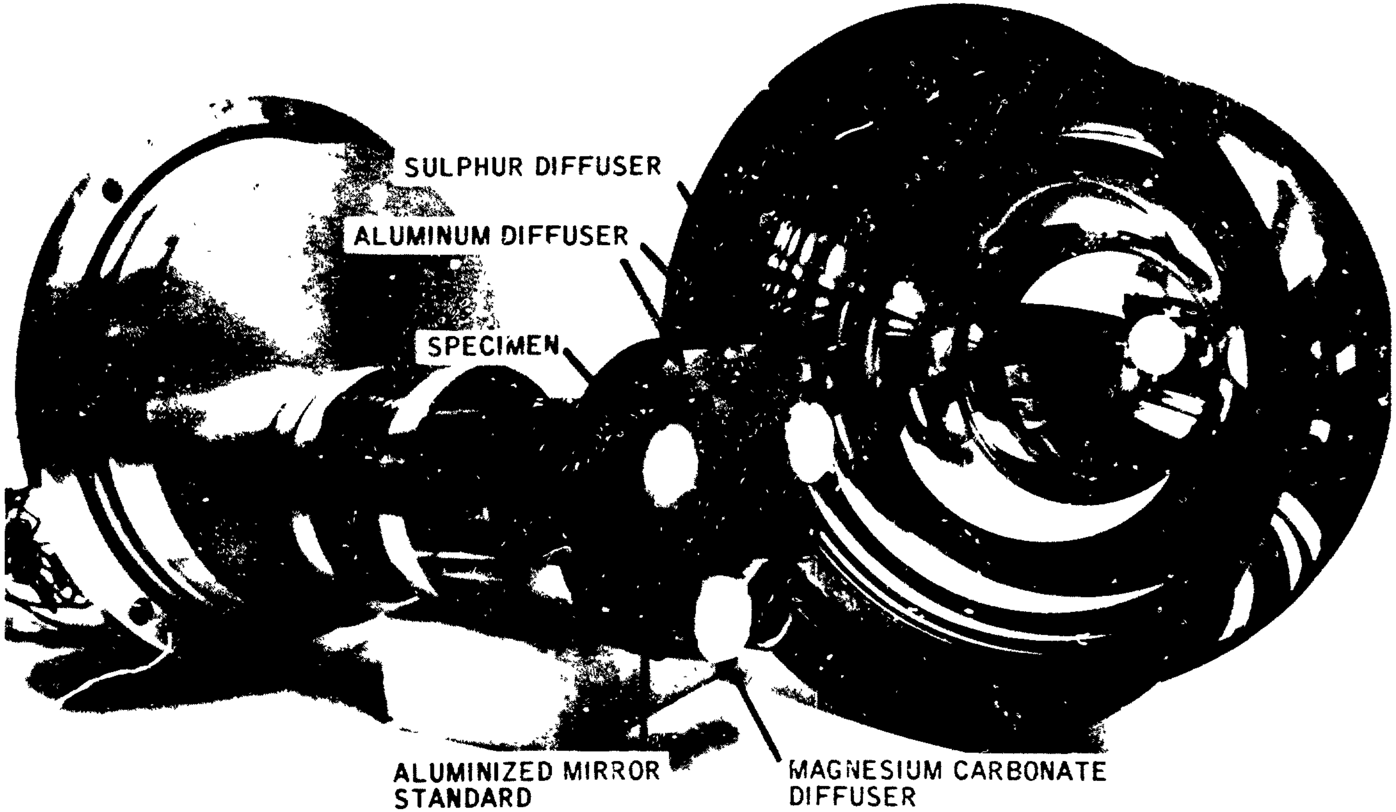


Figure 4 - HEMISPHERE AND TURRENT

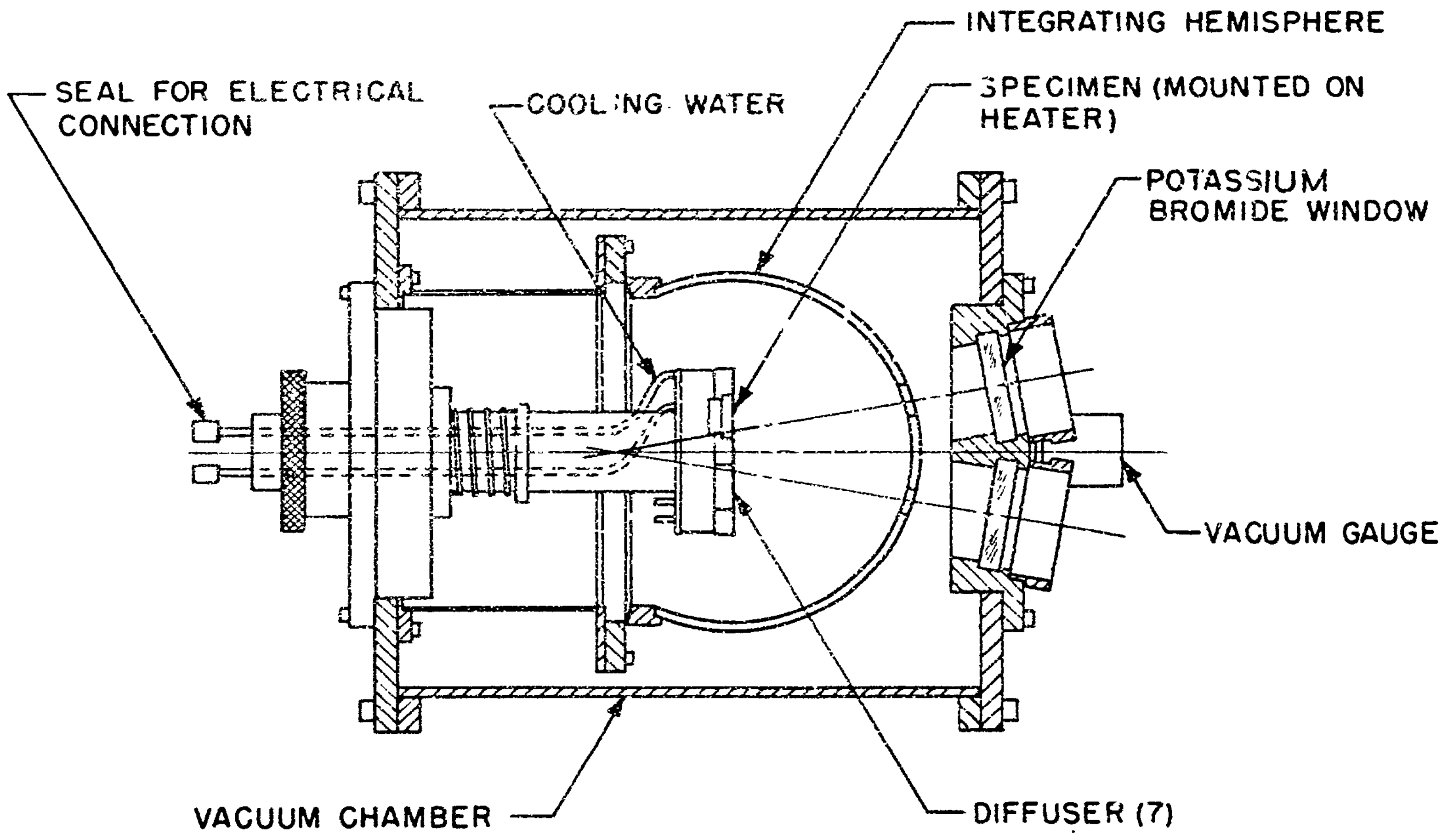


Figure 5 - VACUUM CHAMBER AND HEMISPHERE

The vacuum chamber and pump assembly constructed for the black-body reflectometer were also used with the integrating hemisphere. The chamber was a brass cylinder 12" diameter by 15" long. A 4" diam. tee connection fastened directly to the vacuum valve. The liquid nitrogen cold trap, water-cooled oil vapor baffel, and 4 in. oil diffusion pump were connected directly below the vacuum valve as shown in Figure 6. A large capacity fore pump was provided as a back-up for the diffusion pump. This arrangement of large-diameter, short connections provided maximum pumping speed. From a cold start, the system could be pumped down to a pressure of 10^{-5} mm Hg in approximately one hour. If the diffusion pump was pre-heated, this time was reduced to 10 minutes.

The vacuum chamber, valve, pump, optical system, and associated equipment were mounted on a steel framework (Fig. 6) which was in turn bolted to the console of the spectrometer. The whole assembly was raised off the floor on screw jacks to achieve and maintain the desired optical alignment.

The optical system is shown in Figure 7. Since a globar did not provide enough energy at the short wavelengths, it was necessary to provide a tungsten ribbon filament lamp for the visible region. A two position, mirror was provided for switching from one source to the other (Section A-A, Figure 7). The slit on the entrance system was mounted in a 5/8" diam. brass tube which was cemented in a hole in the middle of the double sided 45° mirror. This mirror was aluminized on both sides. Two 6 in. diam. f/1 spherical mirrors were required to produce an image of the source slit on the diffuser. The image was about 1/8" wide by 5/8" long, and in line with a horizontal line connecting the center of the diffuser and specimen.

Energy reflected from the specimen out the exit aperture was deflected by a plane mirror to a 6 in. f/2.5 spherical mirror; it then passed through a beam rotating mirror arrangement (Section B-B Fig. 7) and finally was focused by the spectrometer source parabola onto the spectrometer entrance slits. The

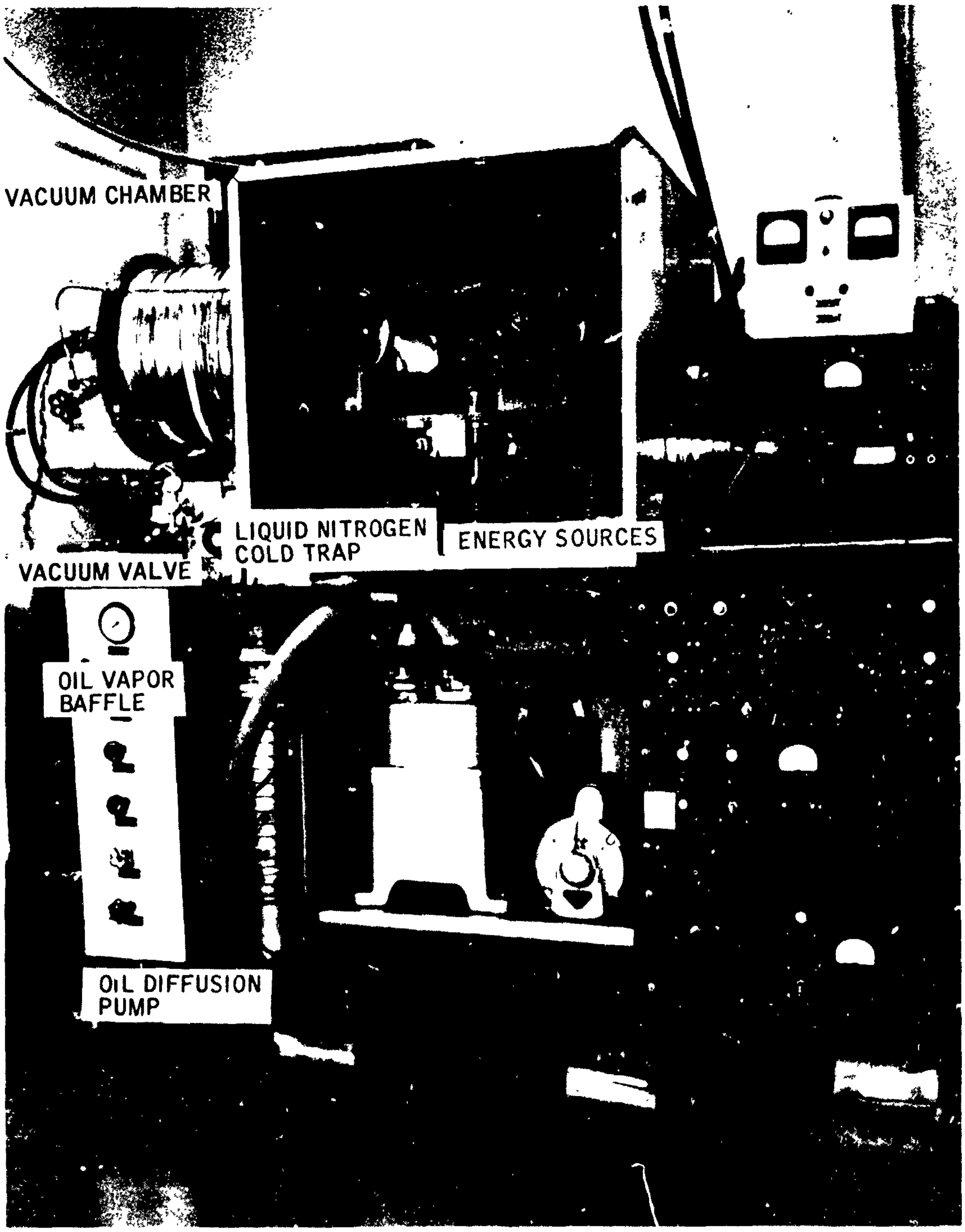


Figure 6 - INTEGRATING HEMISPHERE REFLECTOMETER

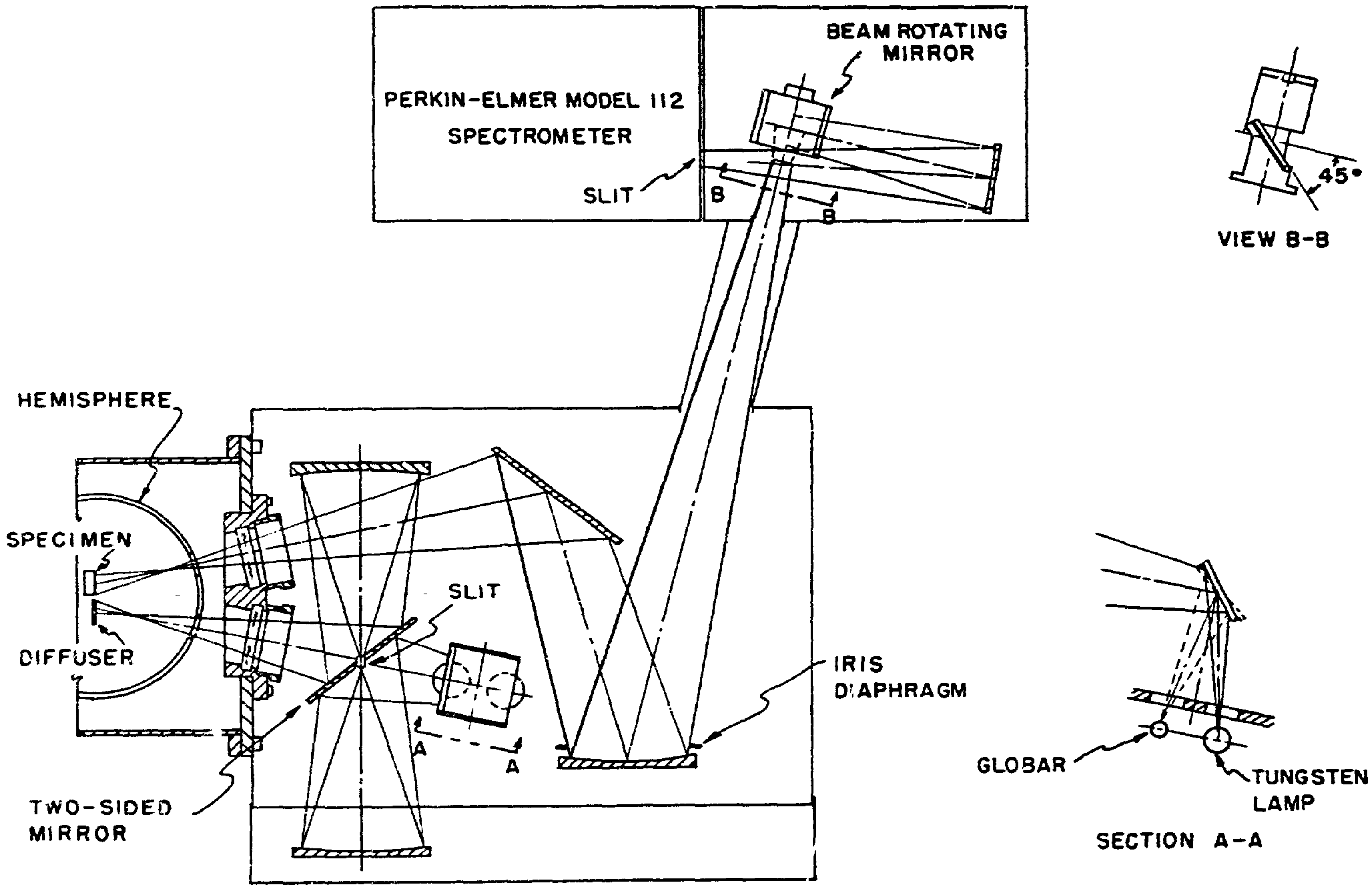


Figure 7 - REFLECTOMETER OPTICAL SYSTEM

images on the diffuser and specimen were horizontal and the spectrometer slits were vertical. Therefore, it was necessary to incorporate a beam rotating mirror in the optical system. Horizontal in-line images were used to reduce the effect of spherical abberation.

Provisions were made for adjusting all of the mirrors to achieve proper optical alignment. The sources and mirrors, with the exception of the beam rotating assembly and spectrometer source parabola, were all mounted on a single 1/2" thick aluminum plate to insure alignment. The entire optical system was enclosed in a light-tight housing which was kept dry with a pan of silica gel.

The sodium chloride prism was used in the spectrometer for the region from 0.4 to 10 microns, and the potassium bromide prism was used from 10 to 24 microns. A 1P21 photo multiplier was used as a sensor for the 0.4 to 0.8 micron region and a Reeder vacuum thermocouple was used for the region from 0.8 to 24 microns.

The tungsten lamp was used as the energy source for the 0.4 to 1.0 micron region and the globar for the remainder of the spectrum.

Hemisphere Calibration

It will be recalled from equations (10) and (13) that the spectral reflectance of the specimen, ρ_s, could be determined by the ratio of signals $\frac{G_{ds}}{G_{dd}}$ and also from $\frac{G_{ds}}{G_{dh}}$, at any particular wavelength provided ρ_h, ρ_d and n were known. The hemisphere reflectance, ρ_h, was measured by an absolute method, and ρ_d was then measured relative to ρ_h utilizing the integrating hemisphere reflectometer.

The reflectance of the aluminized hemisphere was measured using a slight modification of Strong's method (5). With this method the specimen (No. 2) and two identical mirrors (No. 1 and 3) were located as shown in Figure 8.

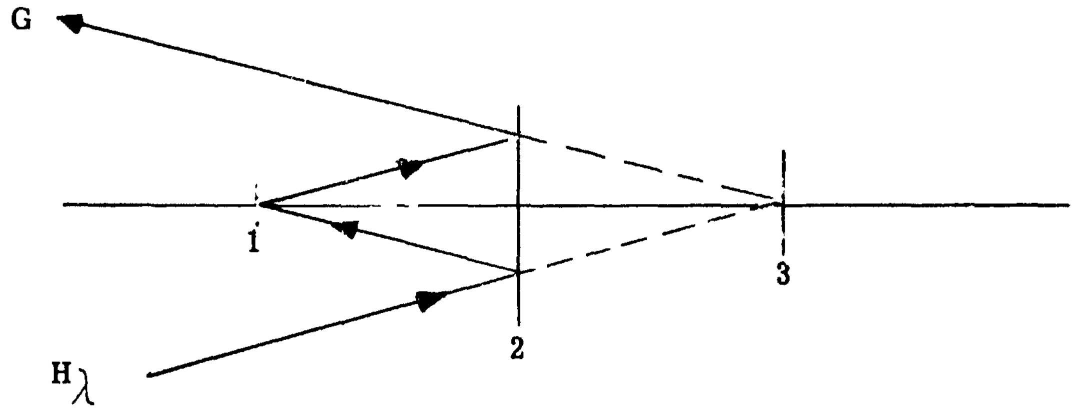


Figure 8 - HEMISPHERE REFLECTANCE DETERMINATION

The specimen (No. 2) was located midway between 1 and 3 as recommended by Strong, so that two reflections from No. 2 occurred. Care was taken to align all three surfaces in parallel planes. When the specimen surface was in place as shown, the energy reflected, G_2, was given by:

$$G_2 = \rho_1 \rho_h^2 \; H_\lambda \tag{16}$$

When the specimen was removed a reference measurement was obtained.

$$G_r = \rho_3 \; H_\lambda \tag{17}$$

Since mirrors No. 1 and 3 were identical, $\rho_1 = \rho_3$ and the reflectance of the specimen of hemisphere material (aluminized glass) was given by:

$$\rho_h = \sqrt{G_2/G_r} \tag{18}$$

Measurements were made by this technique and by a second method with twice the sensitivity. In the second case, the specimen was located 1/3 of the distance from 1 to 3 as snown in Figure 9.

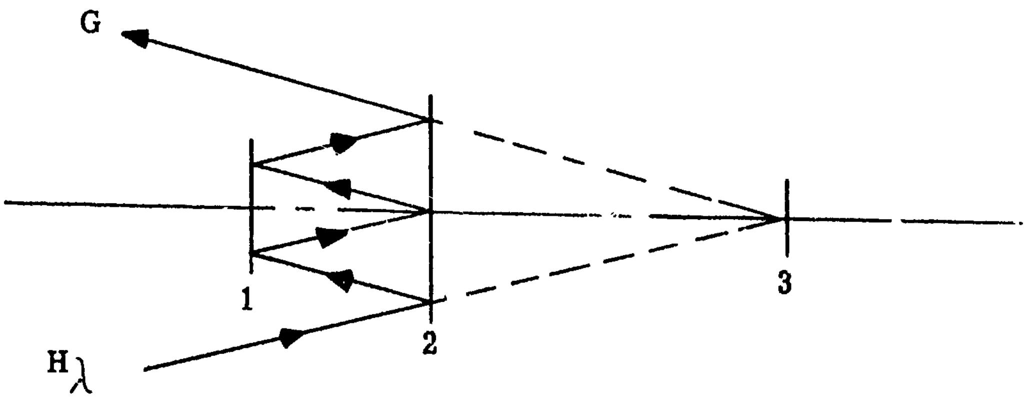


Figure 9 - HEMISPHERE REFLECTANCE DETERMINATION

Three reflections from No. 2 occurred with this arrangement and the energy reflected from the specimen was:

$$G_4 = \rho_1^2 \; \rho_h^3 \; H_\lambda \tag{19}$$

In this case mirrors 1 and 3 were the same material as the specimen.

When the specimen was removed the reference measurement was the same as before and the reflectance then was given by:

$$\rho_h = \sqrt[4]{G_4/G_r} \tag{20}$$

The apparatus used for these measurements is shown in Figure 10. This assembly was mounted from the rear end plate of the vacuum chamber after first removing the hemisphere.

Certain problems were encountered in this measurement which were not present in the other measurements. Since the surfaces were all specular and the optical lever arm was quite long, optical alignment of the surfaces was critical. The mirror mount was designed so that the assembly could be removed from the vacuum chamber and the mirrors were aligned with the aid of a transit and target located about 30 feet from the mirror. In addition the sensor collecting

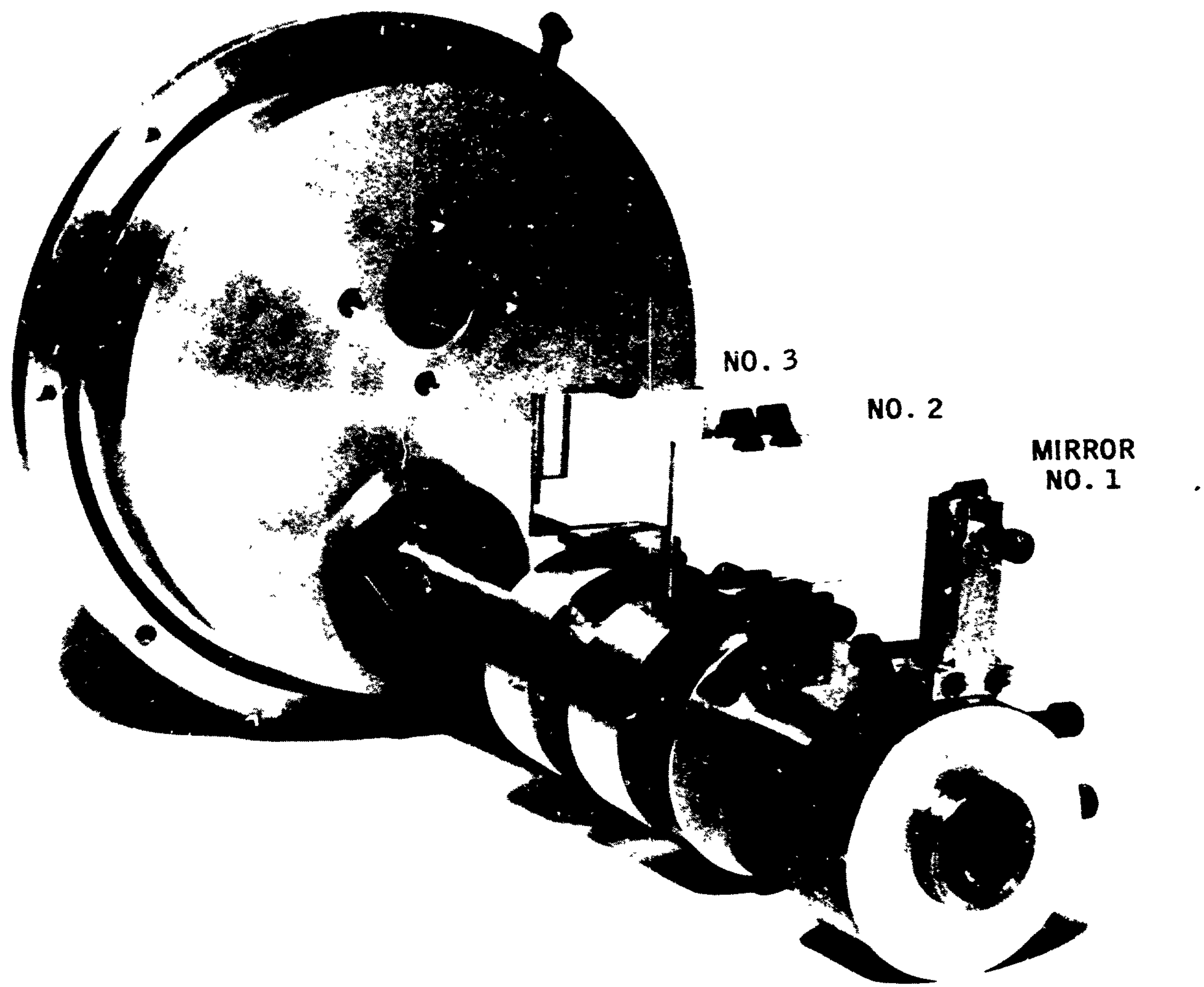


Figure 10 - HEMISPHERE REFLECTANCE MEASUREMENT APPARATUS

mirror was refocused to give a maximum signal each time the mirrors were changed. It will also be noted that the ratio of measured sensor signals appeared under the radical so that any error was further reduced in this manner. Optical alignment was much less critical when measuring the energy reflected from the specimen and diffusers in the reflectometer.

A second problem was that of atmospheric absorption due to water vapor and carbon dioxide. The external light path and the monochromator were flushed with dry nitrogen to reduce absorption effects, but it was difficult to eliminate atmospheric absorption entirely. This was particularly troublesome when measuring the hemisphere reflectance because it was necessary to traverse the spectrum, open the vacuum chamber, change the mirror arrangement, and then make the reference measurement. If the absorption of the external light path changed between the two measurements, an error was introduced. Flushing the light path with dry nitrogen and the use of silica gel appeared to control this problem.

The absorption problem was much less serious when making measurements of the specimens. These measurements were made point by point with the reference measurement being made almost simultaneously. Absorption effects were the same for both the specimen and reference measurements and, therefore, cancelled out in the ratio.

Hemisphere reflectance measurements were made with both mirror configurations described. Reasonably good agreement was obtained between the two techniques. However, since considerably more data were obtained with the 5 reflection case, and the inherent errors in the measurement were decreased by 75% in the reflectance calculation, these data were considered to be more reliable.

The measurements were made in a vacuum of approximately 5 x 10^{-6} mm Hg. The entire optical path outside of the vacuum chamber was flushed with dry nitrogen to minimize carbon dioxide and water vapor absorption. Three prisms were used to cover the range of 0.38 to 24 microns. Quartz was used from 0.38 to 2.0 microns; NaCl from 0.4 to 12 microns; KBr from 2.0 to 24 microns. The vacuum thermocouple sensor was used for the entire range of 0.38 to 24 microns.

The data are tabulated in Table 1 and are shown graphically in Figures 11 and 12. The theoretical reflectance was claculated from the Hagen-Rubens equation for reflectivity of metals in the infrared (6).

$$\rho = 1 - 36.05\sqrt{\frac{r}{\lambda}}$$

where r = specific volume resistivity in ohm-cm

λ = wavelength in microns

The electrical resistivity value of 2.828 x 10^{-6} ohm-cm for commercially pure aluminum at 20 c was used (7).

The data were plotted as shown in Figures 11 and 12 and the best curve was then drawn. It was found that the theoretical curve gave the best agreement with the measurements beyond 2.5 microns. The reflectance at the wavelengths selected for specimen measurements were then read from the curves. These values are presented in Table 3*along with the reflectance of the diffusers.

Calculation of Loss Factor

In the derivation of the equation for the energy reflected to the spectrometer, it was assumed that the distribution of energy reflected by both the diffuser and specimen follow the cosine law. If the energy initially reflected by the diffuser closely approximates a cosine distribution, then all subsequent reflections will approximate the cosine distribution even more closely since

* See Page 39

scattering is an irreversible process and the cosine distribution rep ॰ᵉˢᵉⁿᵗˢ the limit for infinite scattering. The loss factor D was then defined as:

$$D = 1 - F_{di} - F_{de} = 1 - F_{si} - F_{se} \tag{21}$$

F = solid angle factor between the diffuser or specimen and the inlet or exit aperture.

Subscript d refers to diffuser

s refers to specimen

i refers to inlet or entrance aperture

e refers to exit aperture

The solid angle factor between two parallel disks is (4):

$$F = 1/2 \left(x - \sqrt{x^2 - 4\,(r_a/r_d)^2}\right) \tag{22}$$

$$x = 1 + (s/r_d)^2 + (r_a/r_d)^2 \tag{23}$$

r_a = radius of aperture

r_d = radius of diffuser

s = distance between diffuser and aperture

The dimensions were:

r_a = 0.5 in.

r_d = 0.5625 in.

s = 4.678 in.

Therefore

$$F = 0.0111 \tag{24}$$

and $$D = 0.978 \tag{25}$$

TABLE I
REFLECTANCE OF ALUMINIZED HEMISPHERE

QUARTZ PRISM

Wavelength, Microns	Reflectance Run 1	Reflectance Run 2
0.375	0.880	
0.385	0.871	
0.405	0.864	
0.425	0.869	
0.450	0.870	0.878
0.475	0.872	0.875
0.510	0.873	0.877
0.550	0.874	0.876
0.600	0.872	0.872
0.665	0.867	
0.750	0.850	0.849
0.790	0.842	0.839
0.834	0.840	0.831
0.880	0.864	0.862
0.940	0.893	0.892
1.00		0.914
1.06		0.923
1.13	0.928	
1.195	0.924	0.934
1.26	0.936	0.939
1.32	0.935	0.947
1.39	0.955	0.947
1.46	0.941	0.947
1.53	0.945	0.952
1.595	0.943	0.950
1.66	0.946	0.951
1.72	0.945	0.951
1.785	0.948	0.951
1.85	0.948	0.950
1.91	0.946	0.953
1.97	0.951	0.951

QUARTZ PRISM

Wavelength Microns	Reflectance Run 1	Reflectance Run 2
2.025	0.953	0.953
2.085	0.954	0.955
2.16	0.956	0.956

NaCl PRISM

Wavelength Microns	Reflectance Run 1	Reflectance Run 2
1.90	0.966	
2.45	0.967	
3.00	0.974	
3.55	0.972	
4.06	0.974	
4.52	0.969	
4.95	0.973	
5.35	0.976	
7.04	0.982	
7.25	0.983	
7.53	0.988	
7.78	0.976	
8.05	0.978	
8.26	0.979	
8.55	0.978	
8.75	0.977	
9.05	0.978	
9.28	0.981	
9.5	0.983	
9.73	0.980	
9.93	0.983	
10.15	0.983	
10.35	0.981	
10.55	0.981	
10.75	0.983	

NaCl PRISM

Wavelength Microns	Reflectance Run 1	Reflectance Run 2
11.13	0.986	
11.32	0.985	
11.66	0.985	
12.00	0.985	
12.30	0.985	
12.60	0.981	

KBr PRISM

Wavelength Microns	Reflectance Run 1	Reflectance Run 2
1.6	0.963	0.956
2.05	0.969	0.962
2.85	0.968	
3.45	0.955	0.958
4.00	0.981	0.963
5.10	0.972	
6.10	0.968	
7.00	0.959	
7.75	0.975	
8.50	0.980	
9.87	0.980	
11.05	0.981	
12.2	0.983	
13.15	0.984	
14.03	0.986	
14.82	0.981	
15.56	0.986	
16.28	0.987	
17.67	0.986	
18.90	0.988	
20.04	0.996	
21.15	0.998	

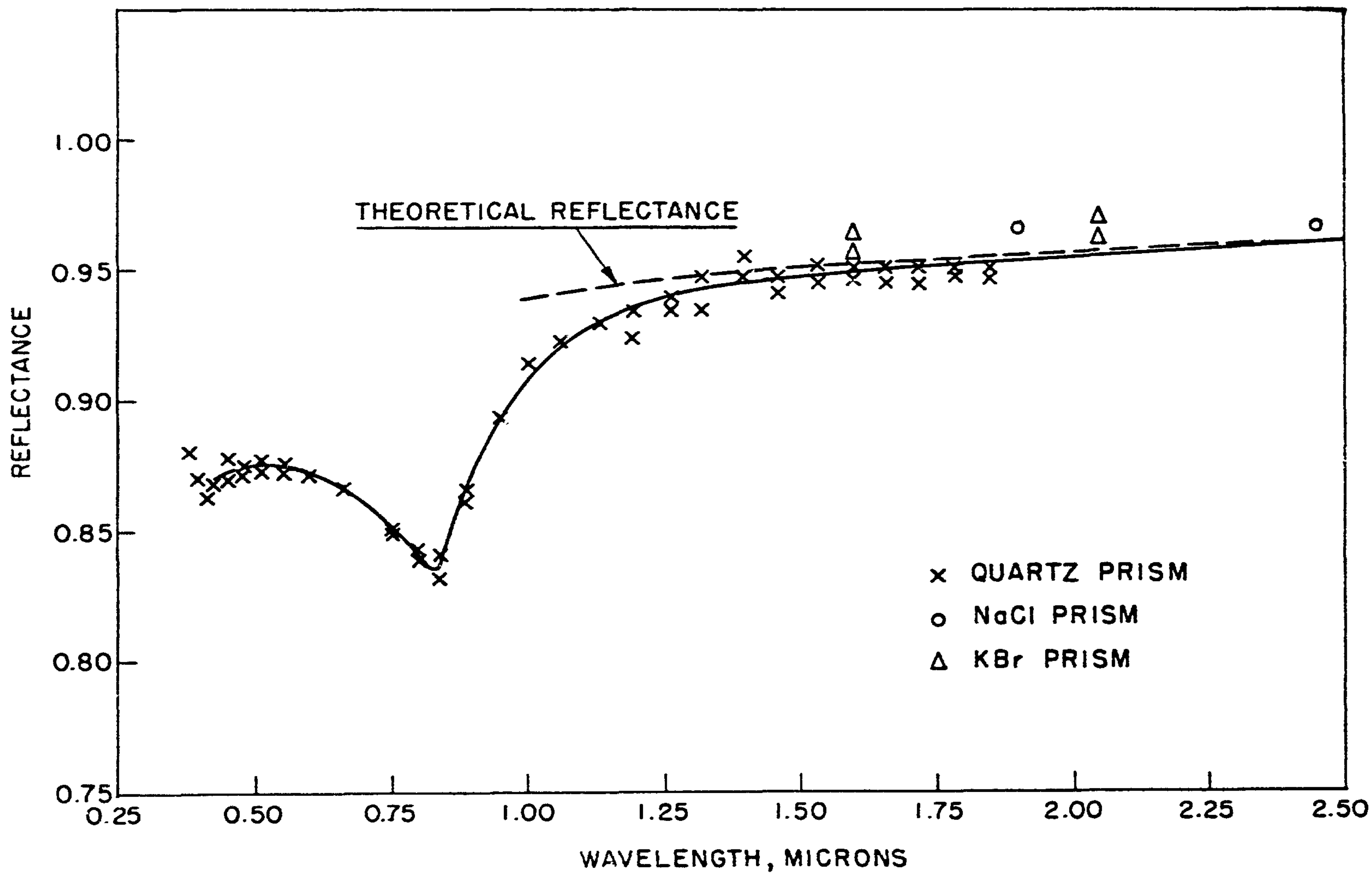


Figure 11 - NORMAL SPECTRAL REFLECTANCE OF EVAPORATED ALUMINUM ON GLASS - .38 TO 2.5 MICRONS

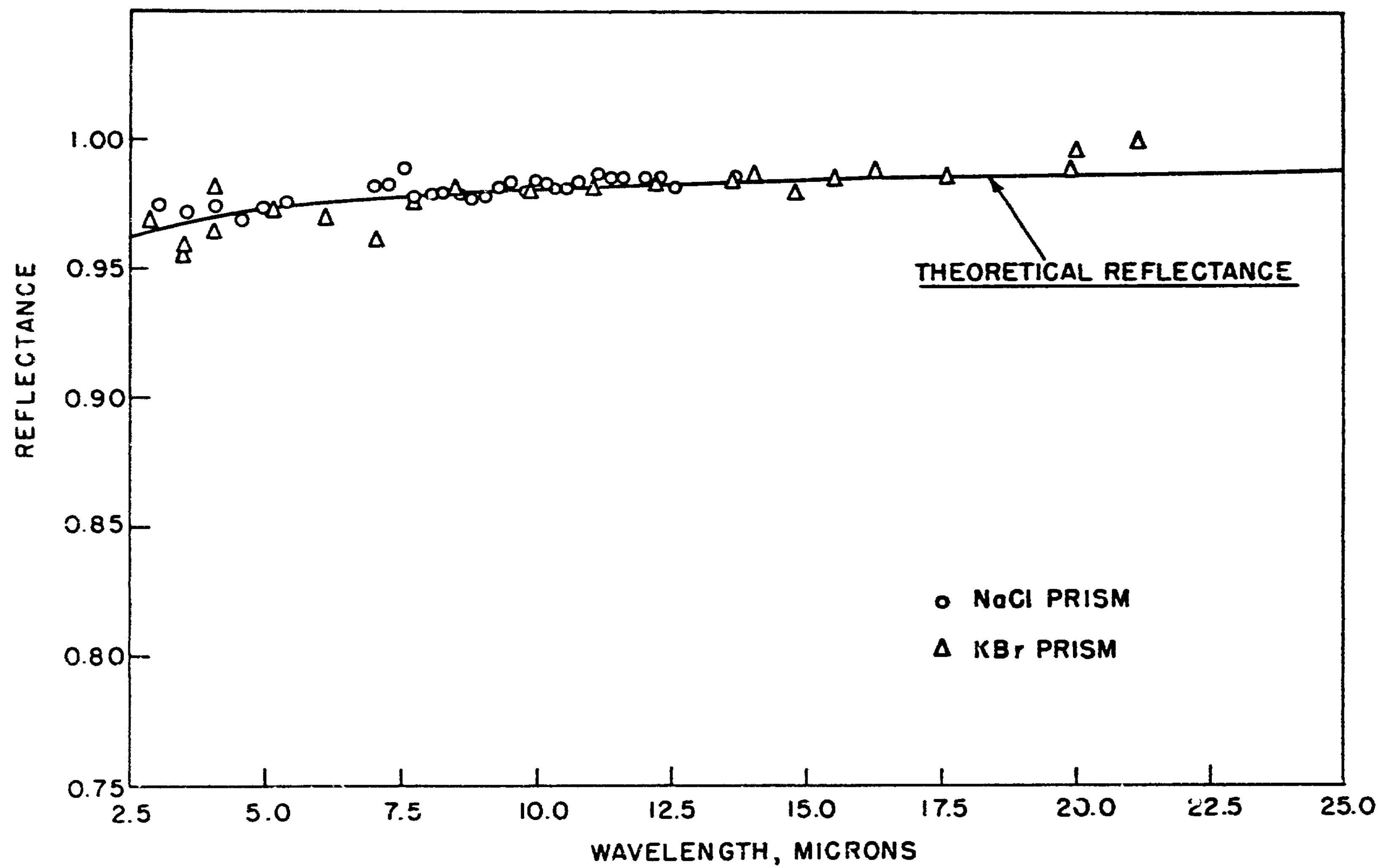


Figure 12 - NORMAL SPECTRAL REFLECTANCE OF EVAPORATED ALUMINUM ON GLASS-2.5 TO 25 MICRONS

Diffuser Calibration

A diffuser of reasonably high reflectance whose surface properties were stable in the vacuum at room temperature was required. It was also necessary that the diffuser reflect according to the cosine law. Sandblasted, corrigated, surfaces of aluminum, stainless steel, and brass were considered. The reflectance of the stainless steel diffuser was about half the value of the aluminum and would have made a useful diffuser for specimens with a low reflectance. Unfortunately it was quite specular beyond about 10 microns and was rejected. Brass also had a lower reflectance than aluminum in the visible region but was very similar in the infrared and offered no advantages over aluminum.

In an effort to assure better scattering of the energy incident on the diffuser, concentric corrigations 0. 008 in. deep by 0. 040 in. from crest to crest were machined in the surface. The diffusers were then blasted with coarse silicon carbide, dipped in 35% nitric acid, washed and dried in alcohol. Figure 13 shows the diffuser configuration.

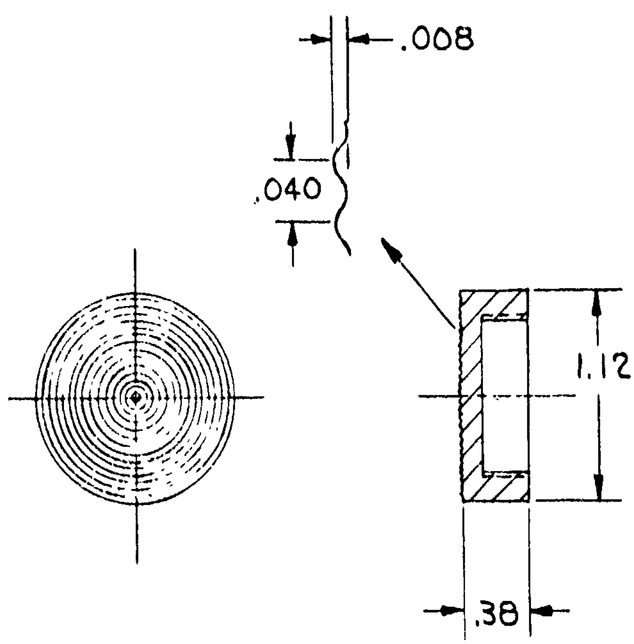


Figure 13 - Diffuser

The degree of diffuseness of the diffusers was measured for the reflection of visible light. A tungsten lamp with a projection lens and a photomultiplier were mounted on a goniometer. Light from the lamp was focused on the various diffusers at an angle of 10° from the normal to the diffuser surface, and the relative energy reflected at various different angles was measured. The results are shown in Figure 14.

The curves follow the cosine law quite well and show negligible specular reflection. The experimental set-up was changed for measurements in the negative quadrant, and this probably accounts for the difference in the relative intensities in the two quadrants. The important observation is the absence of large humps in the curve which would indicate specularity in the reflectance of the diffuser.

The reflectance of the diffusers was determined by substituting a second diffuser for the specimen and comparing this to a diffuser and aluminized glass standard. Equation (13) was then written in a slightly different form.

$$\frac{G_{dd}}{G_{dh}} = R_{dh} D \frac{\left[1 - R_{dh} V\right]}{\left[1 - R^2_{dh} V\right]} \frac{\left[1 - (R^2_{dh} V)^{n+1}\right]}{\left[1 - (R_{dh} V)^{n+1}\right]} \tag{26}$$

where

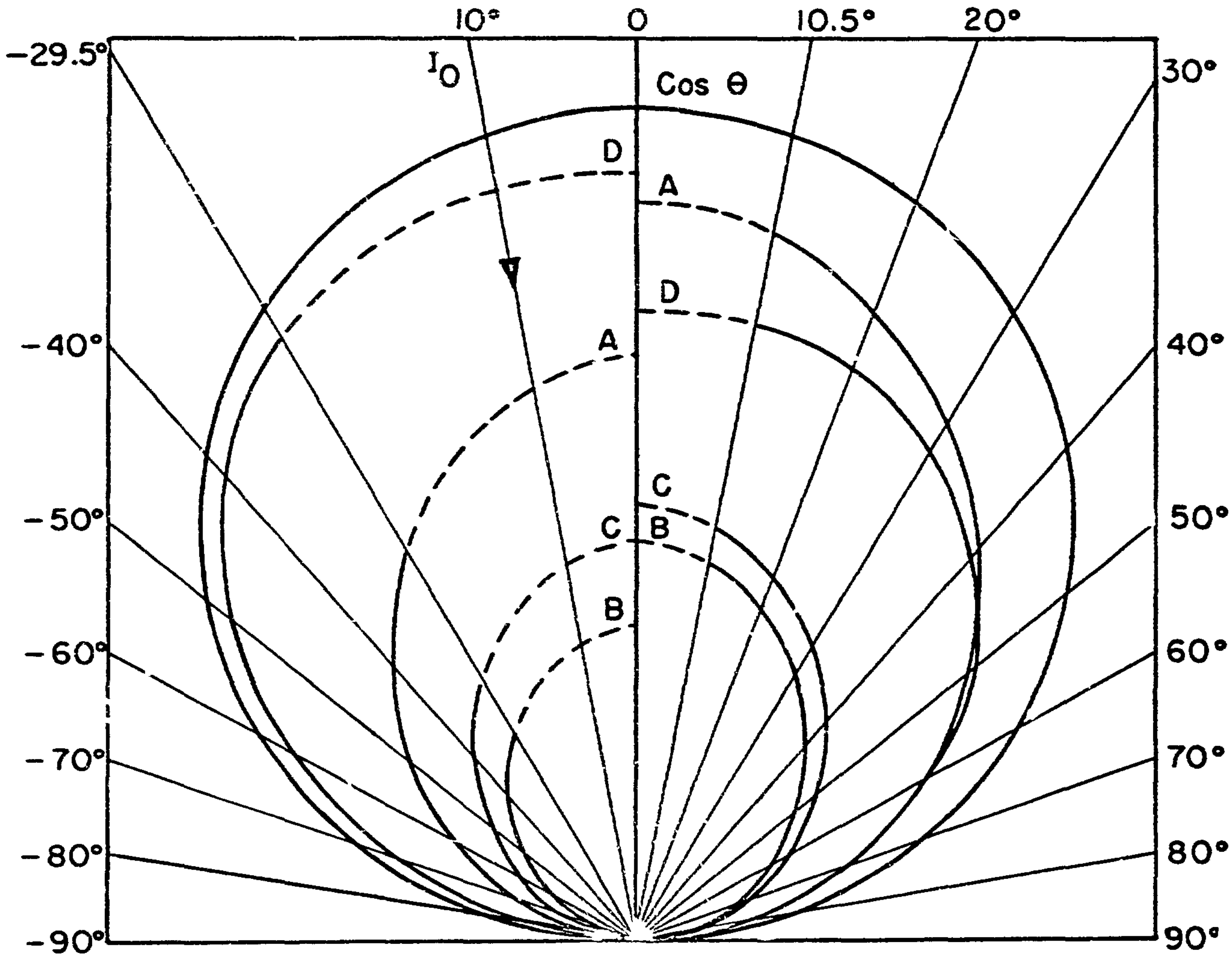
$R_{dh} = \rho_d / \rho_h$

$D = 0.978$

$V = \rho_h^4 D^2$

n = number of internal re-reflections

Since the hemisphere surface reflectance, ρ_h, was known, the reflectance of the diffuser ρ_d could be calculated, if n could be determined.



A — ALUMINUM
B — STAINLESS STEEL
C — BRASS
D — MAGNESIUM OXIDE

Figure 14 - DIFFUSIVITY OF DIFFUSERS

In order to determine ρ_d and n, an intercomparison of measurements was made on three surfaces: aluminum diffusers, sulphur diffusers, and the evaporated aluminum on glass standard. This involved three unknowns: the reflectance of the aluminum diffusers, ρ_a, the reflectance of the sulphur diffusers, ρ_s, and the number of internal reflections, n.

Sulphur was chosen as a diffuser material on the basis of the work reported by Agnew and McQuistan (8) who found sulphur to be the best diffuse reflector in the infrared. Sulphur was found to be a better reflector than the aluminum diffusers out to about 13 microns. However, sulphur has a relatively high vapor pressure and could not be used in the evacuated reflectometer, but it was useful in calibrating the reflectometer.

The sulphur diffusers were formed by first cementing a glass disk to a steel diffuser blank to prevent the steel from reacting with the sulphur. A thin layer of flowers of sulphur was sprinkled on the glass and heated until the sulphur just melted. Sandblasting the glass first helped the sulphur to adhere. A thicker layer of flowers of sulphur was then sprinkled onto the molten sulphur and was tamped to form a solid layer about 1/16" thick. The assembly was then cooled before the tamped layer melted. This procedure gave a sintered surface that could be lightly scraped but would remain intact when held in a vertical position.

When comparing two aluminum diffusers to an aluminum diffuser and the aluminized glass standard, equation (26) became:

$$\frac{G_{aa}}{G_{ah}} = R_{ah} D \frac{\left[1 - R_{ah} V\right] \left[1 - (R_{ah}^2 V)^{n+1}\right]}{\left[1 - R_{ah}^2 V\right] \left[1 - (R_{ah} V)^{n+1}\right]} \qquad (27)$$

where:

$R_{ah} = \rho_a / \rho_h$

$D = 0.978$ (loss constant)

$V \quad = \quad \rho_h^{\,4}\ D^2$

$n \quad = \quad$ number of internal reflections

Subscript "a" refers to aluminum diffuser

"h" refers to hemisphere surface (evaporated aluminum on glass)

When similar measurements were made with the sulphur diffuser, the ratio was given by:

$$\frac{G_{ss}}{G_{sh}} = R_{sh}\, D \frac{\left[1 - R_{sh} V\right]\left[1 - (R_{sh}^{\,2}\ V)^{n+1}\right]}{\left[1 - R_{sh}^{\,2}\ V\right]\left[1 - (R_{sh}\ V)^{n+1}\right]} \tag{28}$$

Subscript "s" refers to sulphur diffuser

The third measurement was made with one sulphur and one aluminum diffuser compared with the sulphur diffuser and aluminized glass standard.

$$\frac{G_{sa}}{G_{sh}} = R_{ah}\ D \frac{\left[1 - (R_{ah}\ Z_h)^{n+1}\right]\left[1 - Z_h\right]}{\left[1 - R_{ah}\ Z_h\right]\ \left[1 - Z_h^{\,n+1}\right]} \tag{29}$$

This is the same as equation (13) except for a change in subscripts. Here subscript s refers to the sulphur diffuser rather than the specimen.

The reflectance of the aluminum diffuser, ρ_a, was then calculated from equation (27) as a function of n using the values for ρ_h read from the curve in Figure 11 and 12 and presented in Table 2. Similarly the reflectance of sulphur, ρ_s, was calculated from equation 28 as a function of n. These values of ρ_s and n were then used in equation (29) to determine the reflectance of the aluminum diffuser with a sulphur diffuser.

Similar measurements were made over the 0.5 to 2.0 micron region using a magnesium carbonate diffuser in place of sulphur. A 3/16 in. thick by 1-1/8 in. diam. disk of magnesium carbonate was used for this measurement. In all cases the best agreement among the measurements occurred at $n = \infty$. This was reasonable since every effort had been made to maximize n.

Table 2 presents a comparison of the measurements on the aluminum diffuser for $n = \infty$. The agreement is quite good out to 2 microns. At 4 microns and beyond the sulphur data was 0.1 higher. This indicated that perhaps the aluminum diffusers were slightly specular at the longer wavelengths. This problem was compensated in the following way. If the specimen to be measured was very specular, then the reference measurement was made with the diffuser and an aluminized glass standard. The specularity of the specimen was then offset by the specularity of the reference. If the specimen was very diffuse, then the reference measurement was made with two diffusers. Since all of the specimens tend to be partially specular, it is believed that the uncertainty was less than indicated in Table 2.

Having determined that an infinite series should be used to describe the interreflections in the hemisphere, equations (10) and (13) respectively were reduced to:

$$\frac{G_{as}}{G_{aa}} = R_{sa} \frac{1 - Z_a}{1 - R_{sa} Z_a} \tag{30}$$

and

$$\frac{G_{as}}{G_{ah}} = R_{sh} D \frac{1 - Z_h}{1 - R_{sh} Z_h} \tag{31}$$

where $R_{sa} = \rho_s / \rho_a$

$R_{sh} = \rho_s / \rho_h$

$$Z_a = \rho_a^2 \rho_h^2 D^2$$

$$Z_h = \rho_a \rho_h^3 D^2$$

Subscript s refers to specimen

a refers to aluminum diffuser

h refers to aluminized glass standard

Equations (30) and (31) have the same general form and can both be written:

$$S = R \frac{1 - Z}{1 - RZ} \tag{32}$$

where $S = \dfrac{G_{as}}{G_{aa}}$,

$R = R_{sa}$,

$Z = Z_a = \rho_a^2 \rho_h^2 D^2$ for eq. (30)

or $S = (\dfrac{1}{D}) \dfrac{G_{as}}{G_{ah}}$,

$R = R_{sh}$,

$Z = Z_h = \rho_a \rho_h^3 D^2$ for eq. (31).

Equation (32) is plotted in Figure 15 and this set of curves was used for solving equations (30) and (31).

TABLE 2

COMPARISON OF ALUMINUM DIFFUSER REFLECTANCE MEASUREMENTS

	Reflectance of Aluminum Diffuser		
Diffuser Used in Measurement	Aluminum Diffuser	$MgCO_3$ Diffuser	Sulphur Diffuser
Wavelength (Microns)			
0.5	.353	.357	------
0.6	.359	.354	------
0.8	.352	.331	------
1.0	.403	.406	.398
1.6	.484	.514	.506
2.0	.518	.503	.536
4.0	.607		.701
8.0	.683		.781
13.0	.718		.817

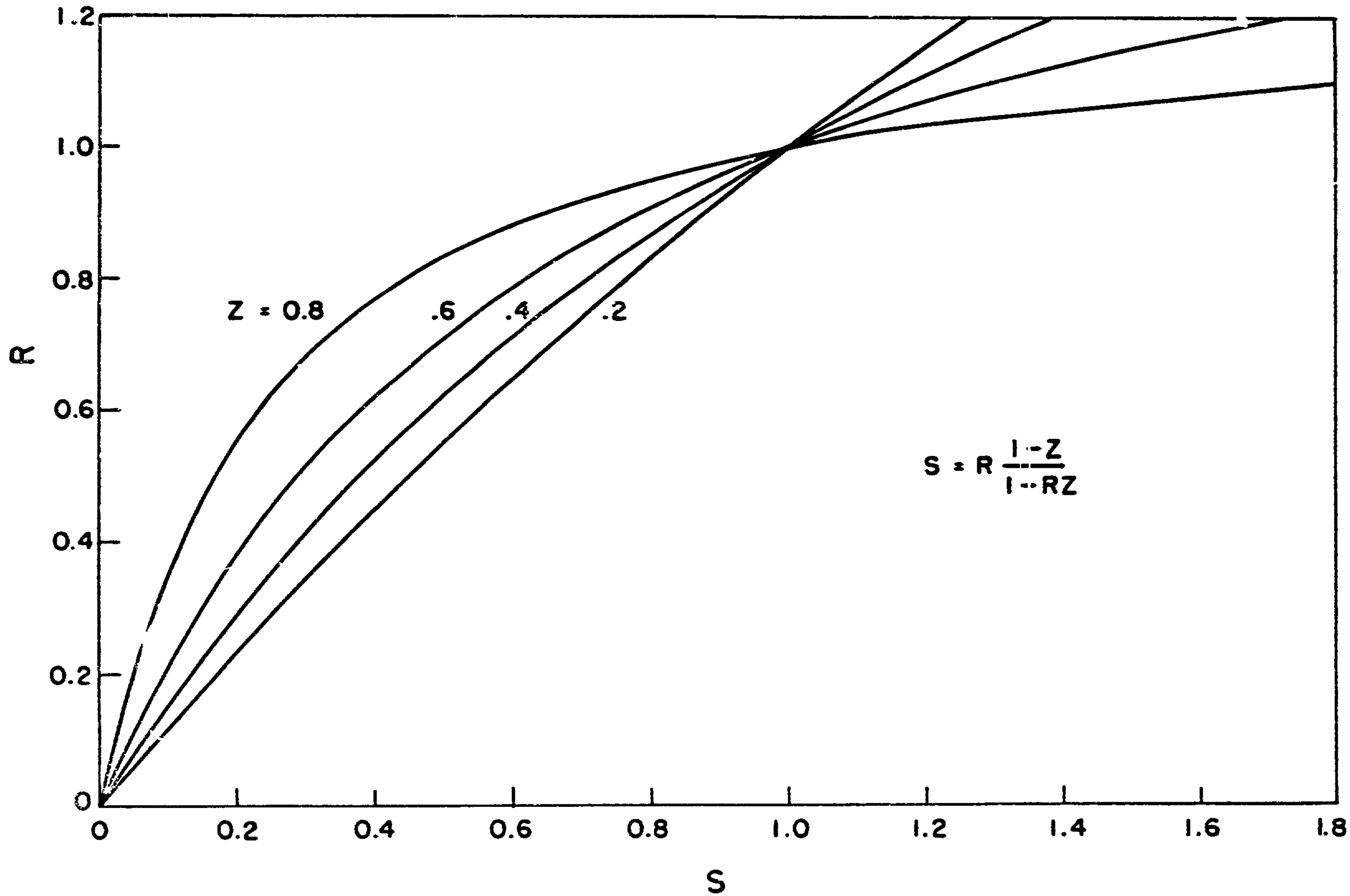


Figure 15 - DIFFUSER CALIBRATION EQUATION

The calibration data used for computing the reflectances of all of the specimens is presented in Table 3 and Figure 16. The values for the aluminized glass standard (and the hemisphere) were read from the curves in Figure 11 and 12. The reflectances of sulphur are as actually measured. The values for the aluminum diffuser were read from a smooth curve drawn through the data as shown in Figure 16.

These data were all computed by hand with the aid of the curves in Figure 15. However, it appeared that data reduction on the large number of specimen measurements was going to be a time-consuming task. Equations (30) and (31) were, therefore, programmed on an IBM 650 computer and all calculations for the specimens were made by the computer.

TABLE 3

REFLECTOMETER CALIBRATION DATA

Wavelength (Microns)	Aluminized Glass (ρ_h)	Sulfur Diffuser (ρ_s)	Aluminum Diffuser (ρ_a)	V	Z_a	Z_h
.38	.873		.330		.079	
.4	.865		.332	.535	.080	.208
.45	.873		.345	.555	.087	.219
.5	.875	.873	.353	.560	.091	.226
.6	.872	.905	.358	553	.094	.227
.7	.861	.917	.352	.525	.087	.215
.8	.841	.893	.351	.478	.084	.209
.9	.875	.944	.370	.560	.100	.237
1.0	.909	.968	.393	.653	.122	.282
1.2	.937	.961	.423	.737	.150	.333
1.4	.945	.970	.446	.762	.170	.360
1.6	.948	961	.466	.772	.187	.380
1.8	.952	.957	.484	.785	.203	.399
2.0	.954	.955	.500	.792	218	415
2.5	.960	.958	.533	.812	.250	.451
3.0	.965	.835	562	.829	.281	.483
3 5	.968	.864	.587	.839	.309	.509
4.0	.970	.899	.608	.846	.333	.531
5.0	.974	.925	.645	.860	.377	.570
6.0	.976	836	.675	.867	.415	.600
7.0	.978	.820	.700	875	.448	626
8.0	.979	.870	.723	.878	.479	.649
9.0	.981	.753	.742	.885	.507	670
10 0	.982	.895	.760	.889	.532	.688
11.0	.983	.889	773	893	.552	.702
12.0	.984	827	.783	896	.568	713
13 0	.984	877	792	896	581	722
14.0	985	.844	.799	.900	.592	730
15.0	.985	.830	805	.900	.601	.735
16.0	985	832	.810	.900	609	740
17 0	.986	898	814	.904	616	746
18.0	986	891	818	904	622	750
19.0	.986	.838	.821	.904	626	752
20.0	.986		823	904	630	754
21.0	.986		825	904	633	.756
22 0	987		827		.637	760

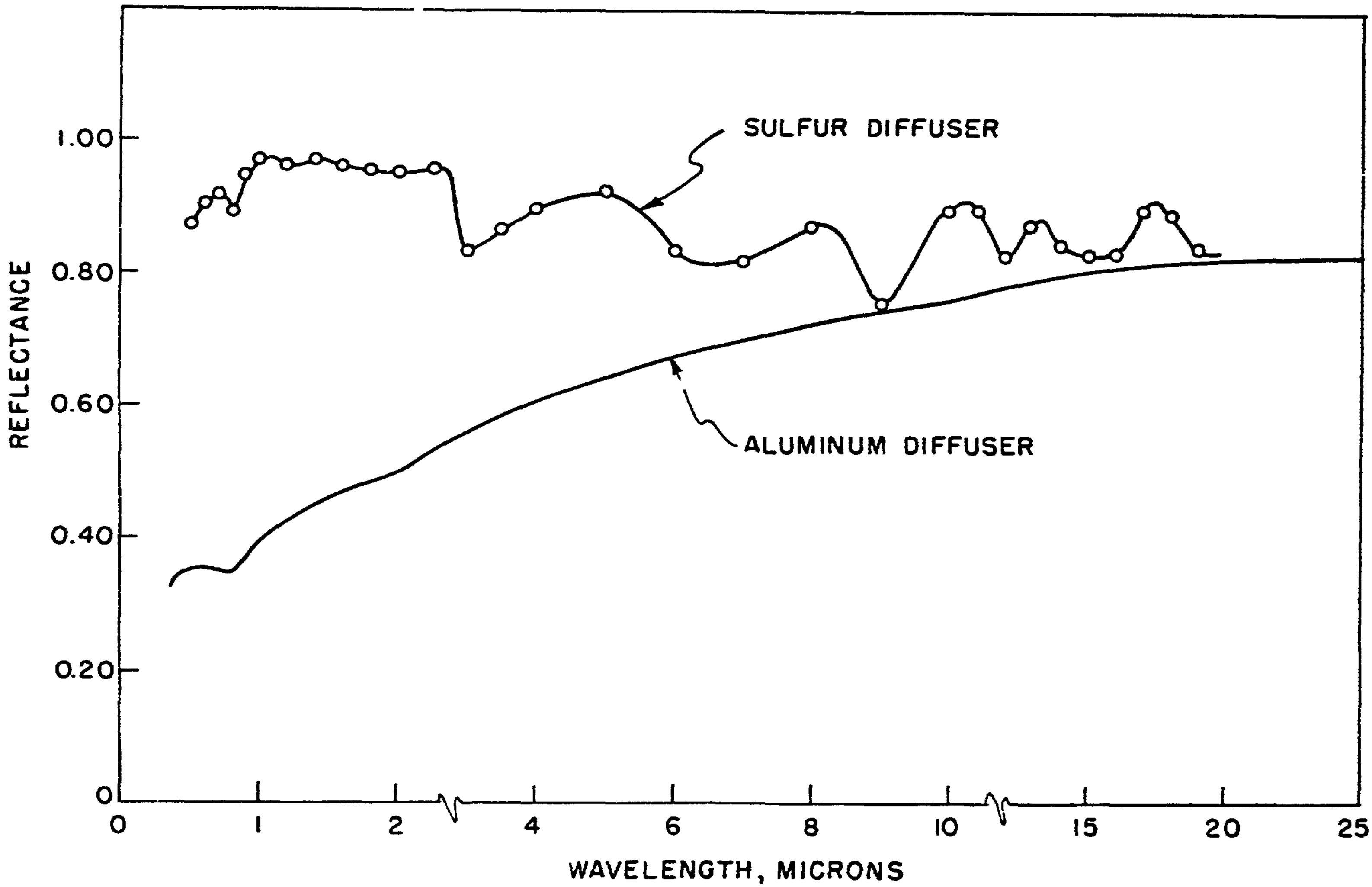


Figure 16 - DIFFUSER REFLECTANCE

Errors

There were several sources of error in the measurements which were very difficult to predict quantitatively. One of the major uncertainties was due to the spherical aberration produced by the hemisphere. This caused the energy reflected from a point on the diffuser to be spread out non-uniformly along a line on the specimen. This line connected the center of the hemisphere to the point where the energy originated. When the energy falling on this line was reflected back to the diffuser, it produced a longer line. The next reflection back to the specimen produced a still longer line which exceeded the size of the specimen and a small amount of energy was lost from the second and each succeeding reflection from the specimen. Consequently the assumption of a simple geometric series with an infinite number of terms was technically incorrect. The use of a series with a finite number of terms was thoroughly studies by intercomparing measurements on several different diffusers as discussed in the section on diffuser calibration. The studies indicated that limiting the length of the initial image projected on the diffuser to about half the diffuser diameter, orienting the length of the image on a line through the centers of the diffuser, hemisphere and specimen and always using maximum slit opening on the spectrometer reduced the spherical aberration error to a negligible amount.

Scattered radiation produced by the windows in the vacuum chamber also was an unknown source of error. It was possible for energy scattered by surface reflections from the entrance window to fall directly on the specimen without first being reflected by the diffuser. This was particularly troublesome in the case of a specular specimen or the aluminized glass standard. In these cases an appreciable amount of energy could be reflected specularly to the spectrometer without first being diffused by the diffuser. To prevent this, it was necessary to tilt the specimen or standard slightly so that the direct reflection of the entrance window did not enter the spectrometer. The reflectometer was originally designed for vertical, parallel images on the diffuser and

specimen and no such problem then existed. However, when the images were rotated 90° to align them and thus reduce the effects of spherical abberrations, the problem of scattering light was aggravated.

A third area of uncertainty was in the diffusers. In the derivation of the equations it was assumed that the reflectance was constant in all directions; i. e., the diffusers reflected according to the cosine law and gave a Lambertiam distribution of reflected energy. The investigation of this problem was covered in the discussion of the diffuser calibration. It was important also that the diffusers did not change with time due to condensation of vapors in the vacuum chamber. The reflectance of the diffusers compared to the aluminized glass standard was, therefore, checked periodically. After some high-temperature runs it was necessary to scrub the diffusers in a detergent, dip in 35% nitric acid, rinse, and dry in alcohol to restore the reflectance to its original value.

Proper focusing of the diffuser and specimen was critical. The hemisphere had a very shallow depth of field and it was necessary to locate the surface of the specimen and diffuser within a few thousandths of an inch of a plane passing through the center of the hemisphere. It was found that the turret could be adjusted with the focusing nut to give a maximum signal and the position of the nut could be marked. Locating the proper position for both the specimen measurement and the reference measurement in this way gave 99% or greater reproducibility in most cases. Good reflectors were more critical in this respect than poor reflectors.

The amplifier and sensor noise also were sufficient to limit measurement accuracy at low energy levels where a high amplifier gain was required. This was especially troublesome when the specimen to reference reflectance ratio was small. When the specimen reflectance was only 10% of the reference reflectance (diffuser or aluminized glass standard) the instrument recording error could be 10% of this ratio Zero drift in the instrument was also annoying at high gains, necessitating repetitive readings to obtain a reproducible zero.

Measurements at 0.8 microns were awkward. The spectral response of the photo multiplier dropped off sharply in this region and gave readings of questionable accuracy. On the other hand this represented the lower limit for the thermocouple and required maximum amplifier gain along with maximum noise. Disagreement between the two sensors ranged from zero to more than 25% in a few cases. Although both sensors were used at 0.8 microns, the thermocouple data was considered more reliable and is reported in the tables. Both measurements are shown in the curves.

To get an indication of the over-all accuracy, measurements were compared with those of other investigators. Figure 17 shows a comparison of our measurements on magnesium carbonate, with those of Benford (1) and Betz (9). These data agree within 1.5% except for the measurement at 2.0 microns. Disagreement here may have been due to the wide spectrometer slits we were forced to use to compensate for spherical aberrations and the presence of a narrow absorption band at 2.0 microns. Our spectral resolution probably was not as good as in the case of Betz's measurements.

In addition to this, arrangements were made to have the normal spectral reflectance of anodized aluminum specimens measured at the Solar Radiation Laboratory of the University of California, Los Angeles Branch, and at the Thermophysics Laboratory, Dept. 53-11 of the Lockheed Missiles and Space Division, Sunnyvale, California. Both of these laboratories use a Cary integrating sphere (magnesium oxide coated) for measurements in the range of 0.25 to about 2.0 microns and a Gier-Dunkle black-body reflectometer for the 2.0 to 22 micron region. Unfortunately, the UCLA black-body reflectometer was tied up on other work, and they were able to make measurements only in the short-wavelength region.

The UCLA data on chromic acid anodized 1075 aluminum (Specimen No. 55) and sulfuric acid anodized 7075 aluminum (Specimen No. 63) are presented in Table 4. The UCLA data, the Lockheed data, and our data are compared in Figures

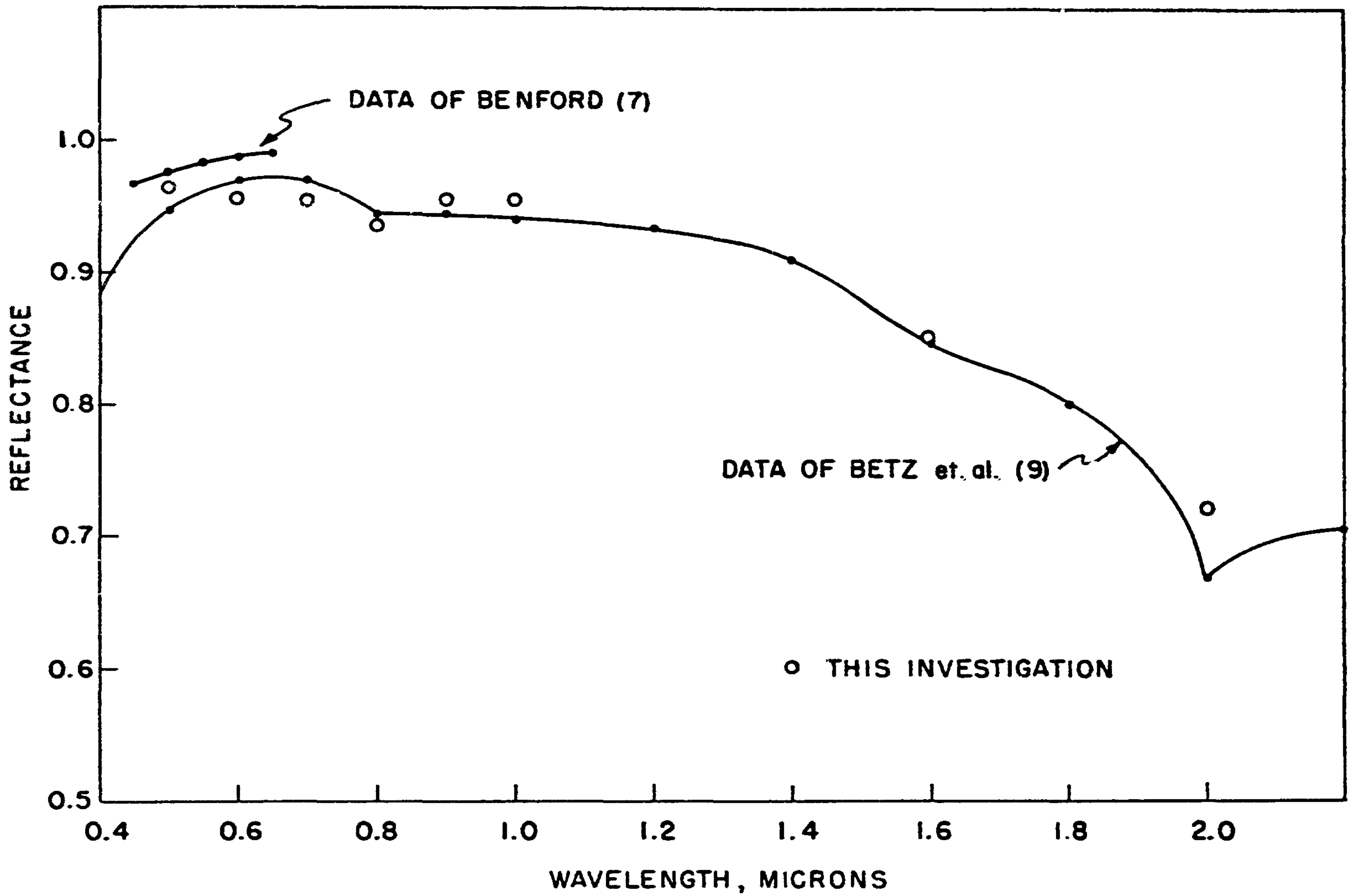


Figure 17 - REFLECTANCE OF MAGNESIUM CARBONATE

TABLE 4

REFLECTANCE OF ANODIZED ALUMINUM MEASURED AT UCLA

Wavelength Microns	Specimen 55	Specimen 63	Wavelength Microns	Specimen 55	Specimen 63
.34	.51	.35	.72	.705	.605
.37	.54	.40	.75	.745	.60
.39	.58	.42	.77	.795	.60
.41	.61	.435	.79	.655	.60
.43	.62	.465	.81	.715	.60
.44	.645	.495	.84	.725	.61
.46	.65	.50	.87	.695	.63
.47	.665	.505	.90	.745	.645
.48	.67	.52	.93	.81	.665
.49	.68	.52	.96	.815	.695
.50	.70	.54	1.00	.825	.71
.52	.675	.54	1.04	.875	.715
.53	.71	.55	1.08	.88	.755
.55	.71	.56	1.12	.88	.755
.56	.69	.57	1.17	.90	.78
.57	.735	.58	1.23	.91	.785
.59	.725	.58	1.29	.905	.795
.60	.705	.59	1.36	.915	.80
.62	.735	.59	1.54	.935	.825
.64	.735	.59	1.54	.935	.825
.65	.705	.595	1.67	.925	.82
.67	.725	.595	1.82	.94	.825
.69	.75	.595	2.05	.94	.825
.70	.71	.60			

18 through 22. The specimens measured at UCLA and by us were each punched from the same anodized coupon (No. 55 and 63 respectively). The specimens measured at Lockheed were punched from coupons No. 56 and 64 which we anodized at the same time and should have been identical to 55 and 63 respectively. Lockheed also measured a Martin hard coat anodized 7075 aluminum specimen, No. 88, and we measured a similar specimen No. 87.

The three sets of data are in good agreement in the region below 2 microns. The measurements made at UCLA and LMSD were made with narrower spectrometer slits and at more frequent intervals than ours. The resulution thus achieved revealed absorption bands in the reflectance of specimen 55 and 56 in the region below 1. 2 microns. Since these specimens were anodized in a chromic acid bath, the oxide coating was relatively thin and the specimens were quite specular. The absorptions bands were undoubtedly due to interference effects. The slight phase displacement between 55 and 56 indicates that the oxide coating on 56 may have been slightly thicker. Although our measurements did not resolve these interference bands they did give an accurate average reflectance in this region.

In the region from 2 to 10 microns our data agreed well with the LMSD data for specimen 56. This specimen was measured in air in both cases. In the case of specimen 64, however, our data for both 63 and 64 was appreciably higher in the 4 to 7 micron region. Since our data for both 63 and 64 were taken in vacuum and the LMSD data were taken in air, it is possible that the increased reflectance was due to a loss of water. The high temperature runs on 63 showed that increasing the specimen temperature drove moisture out of the oxide film and raised the reflectance.

Beyond 10 microns our data was consistently higher. This may also have been partially due to loss of water although specimen 56 which was measured both in air and vacuum did not bear this out. The coating on 56 was more dense and contained less water than either 64 or 88, however.

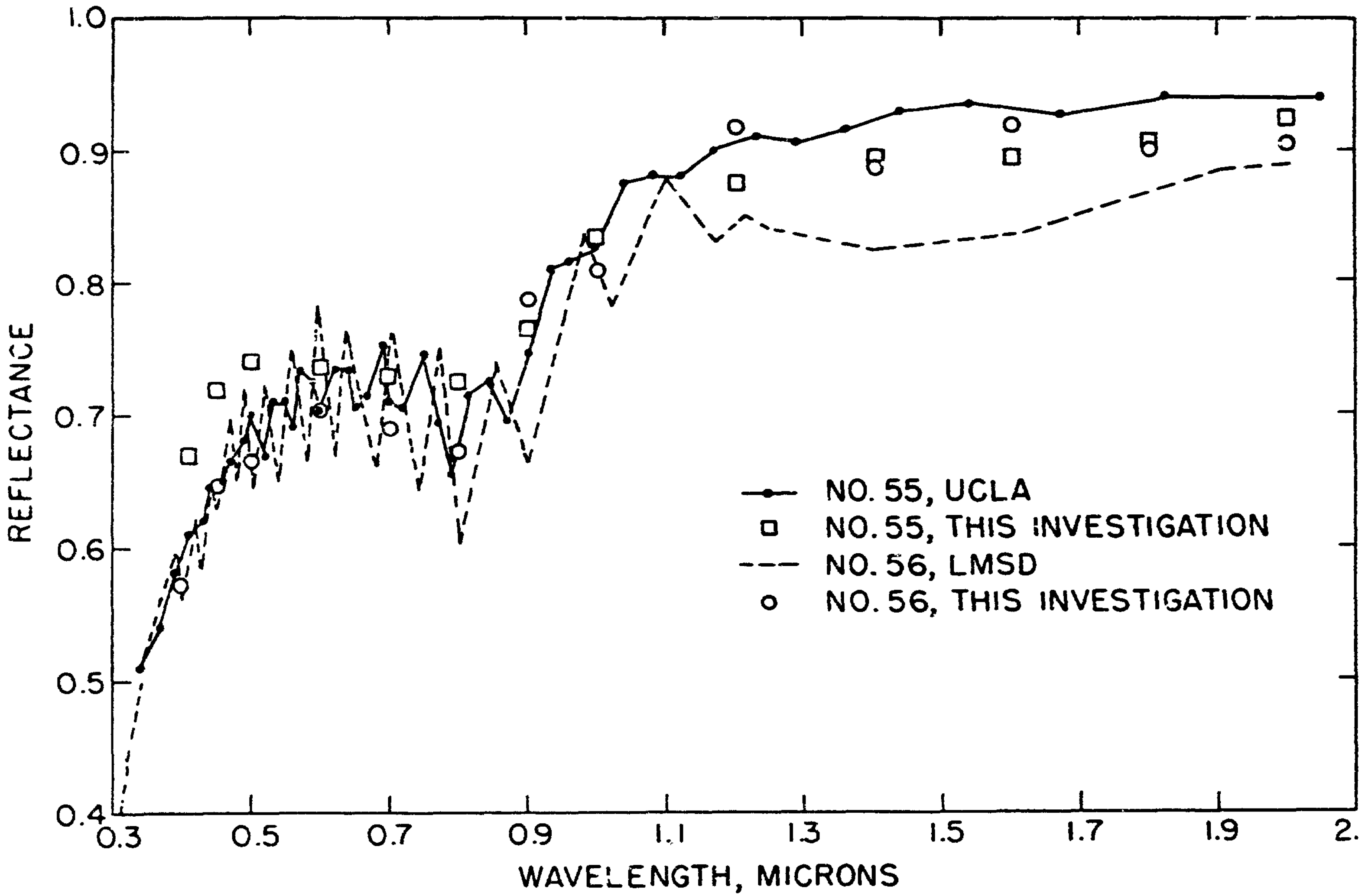


Figure 18 - CHROMIC ACID ANODIZED 1075 ALUMINUM

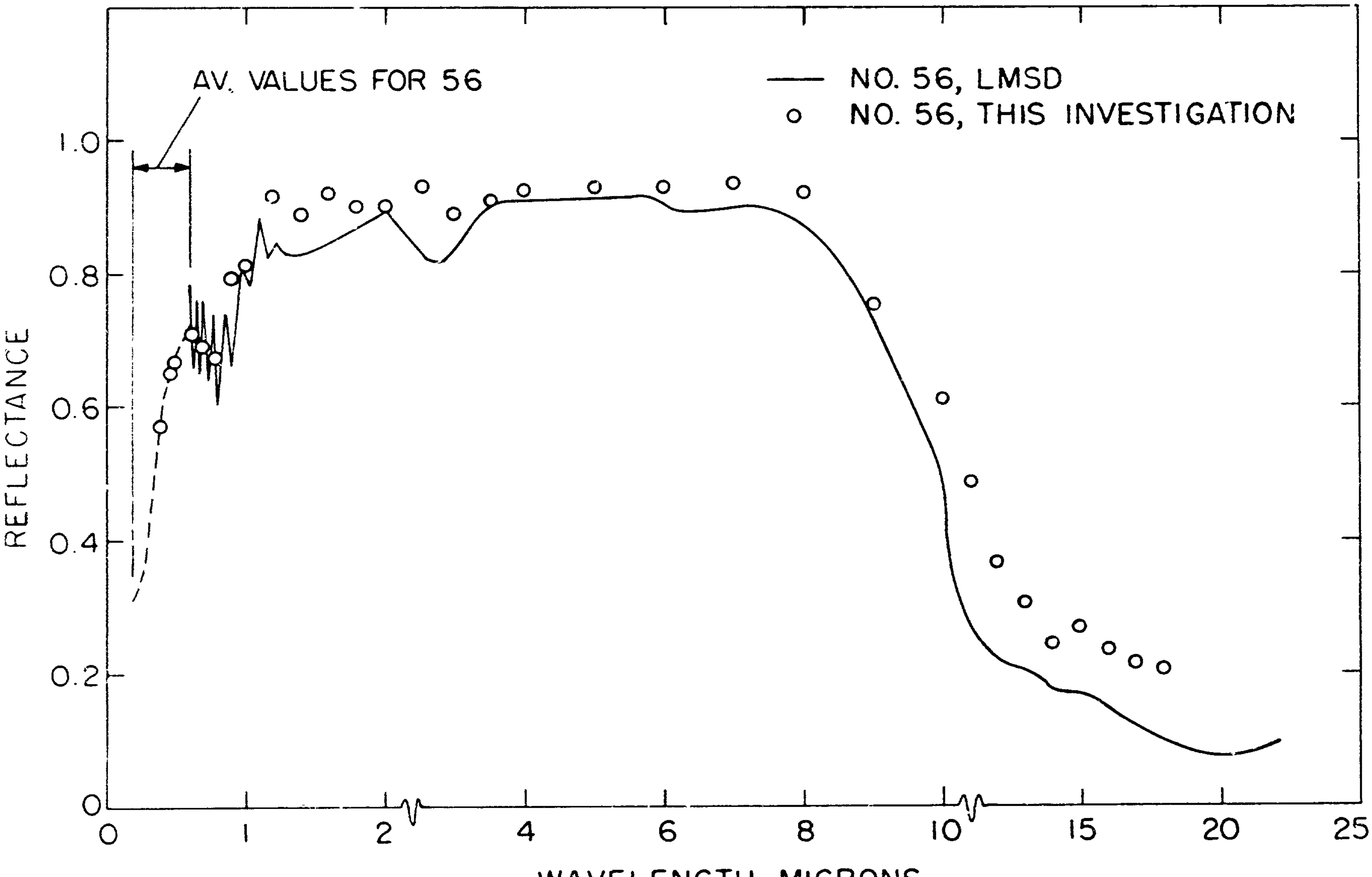


Figure 19 - CHROMIC ACID ANODIZED 1075 ALUMINUM

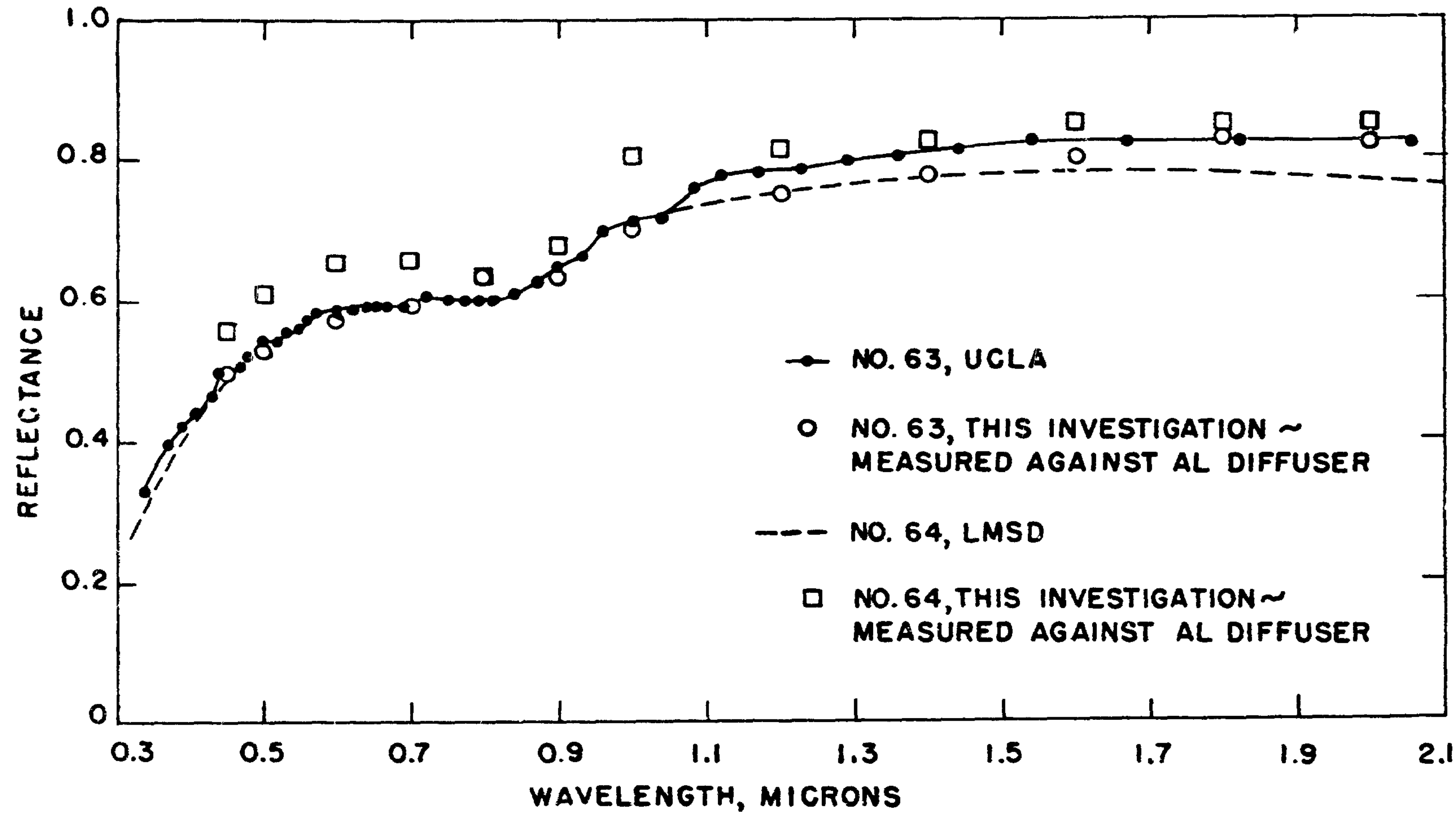


Figure 20 - SULFURIC ACID ANODIZED 7075 ALUMINUM

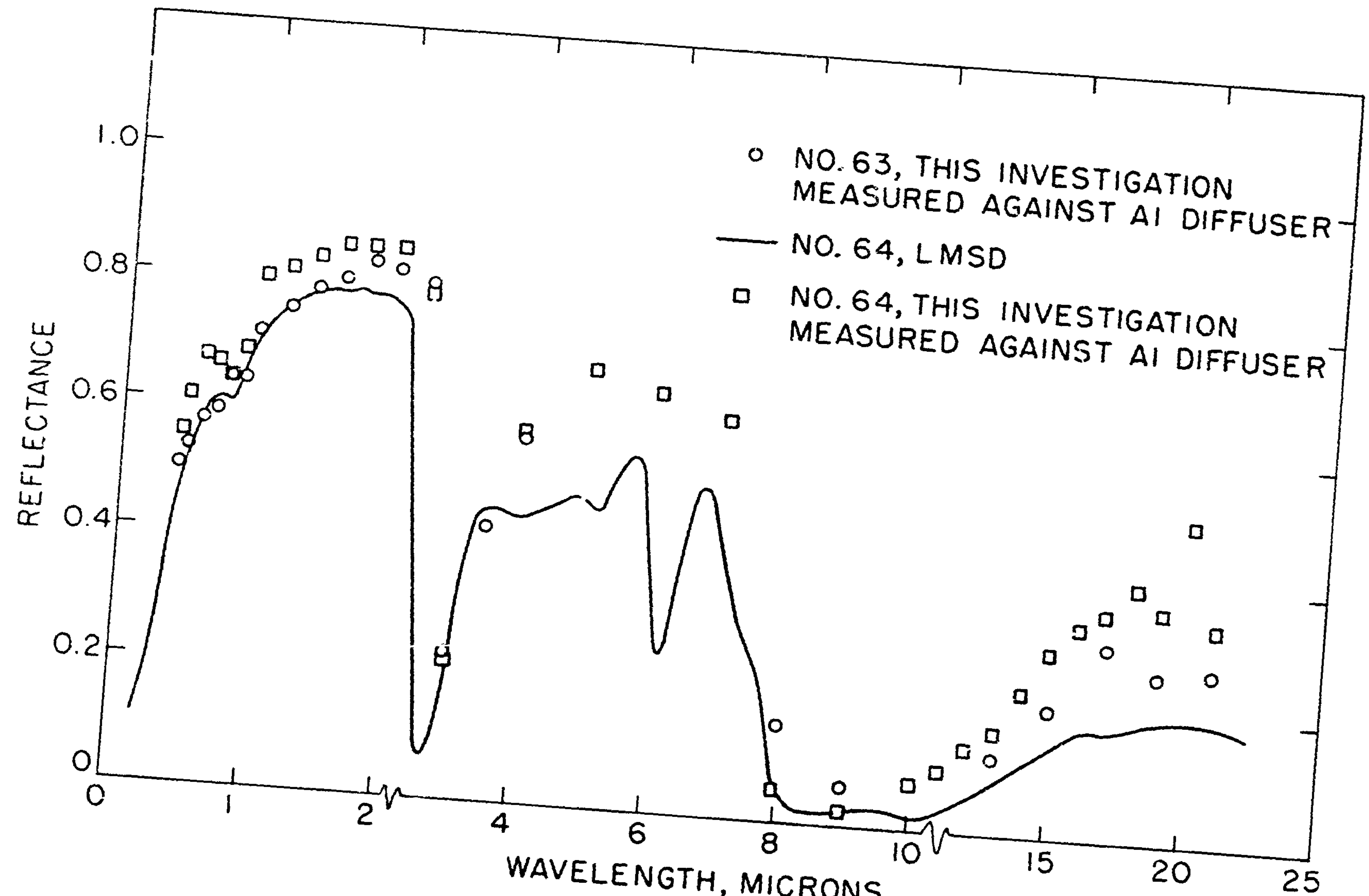


Figure 21 - SULFURIC ACID ANODIZED 7075 ALUMINUM

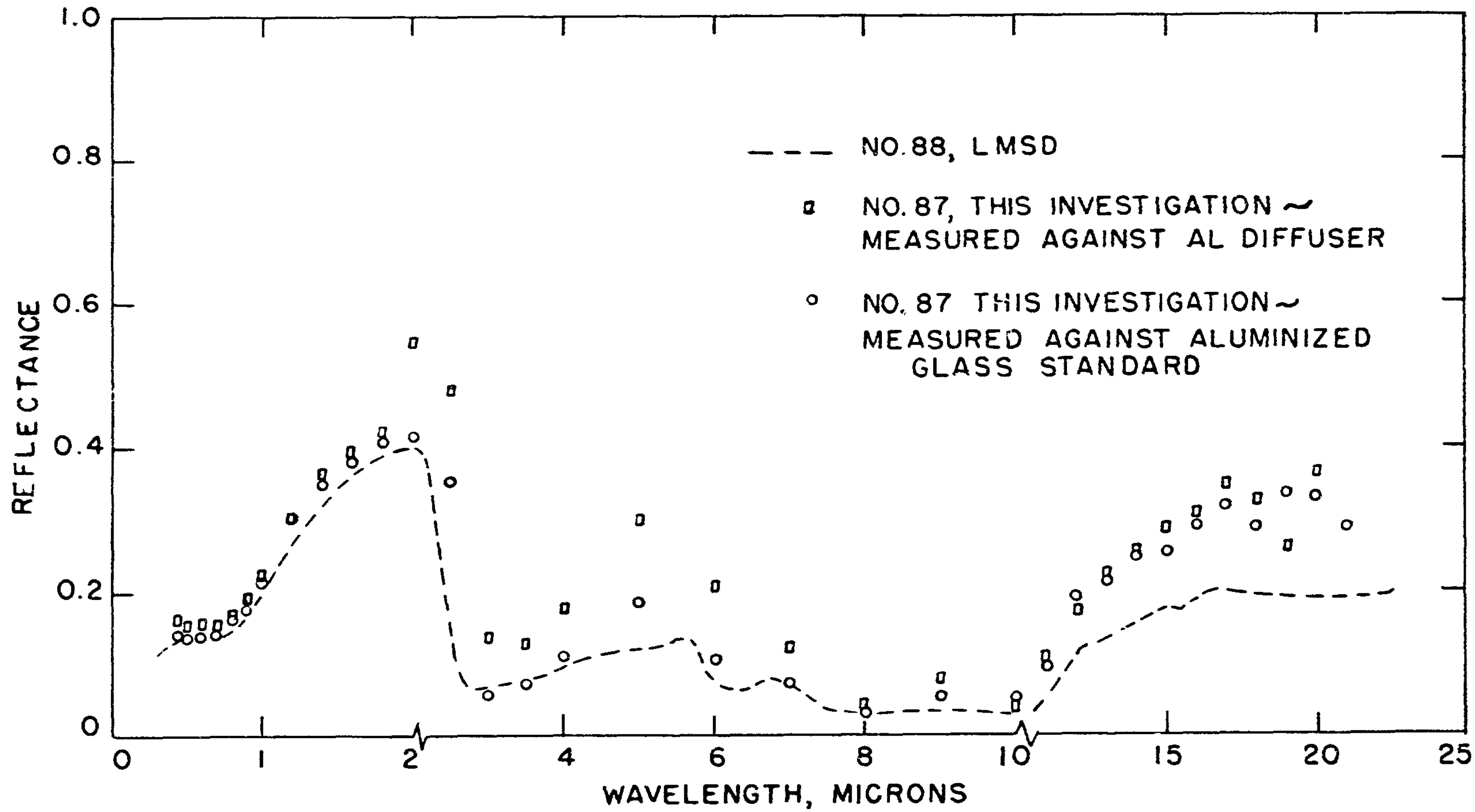


Figure 22 - MARTIN HARD COAT ANODIZED 7075 ALUMINUM

The error problem was probably not quite as severe as it appears. In heat transfer calculations, the engineer is interested in the solar absorptance and infrared emittance values. These are both obtained by subtracting the spectral reflectance values from unity and making the appropriate integrations. An error of even 50% in the measurement of a reflectance value of 10% gives an error of only 5% in the emittance. On the other hand, an error of 1% in the measurement of a reflectance of 90% gives an error in the emittance of 10%. While this error is undesirably high, it should be remembered that in selecting surfaces for space craft, the engineer looks for a high infrared emittance and a low solar absorptance. Solar energy is concentrated in the region below 1. 6 microns where it is extremely difficult if not impossible to make direct emittance or absorptance measurements. In general the engineer must resort to reflectance measurements in this region and accept the inherent error problem. The only alternative is to use calorimetric techniques for the measurement of the ratio of solar absorptance to infrared emittance. If the total emittance is then measured at the same specimen temperature, the solar absorptance can be computed from the ratio. There are several sources of error in these techniques also.

SPECIMEN PREPARATION

Pretreatment - Polishing

Prior to anodizing, the coupons, from which the specimens were punched, were mechanically polished to establish a uniform and reproducible surface. A Lapmaster 12 was used for this work.

An iron lap was initially used with water-mixed lapping compounds; however, the specimens, especially titanium, had a marked tendency to sieze and scratch. A canvas lap with oil-mixed lapping compounds was, therefore, substituted. The lapping compounds were products of the United States Products Company of Pittsburg, Pennsylvania.

The lapping sequence for the various alloys was as follows:

Aluminum 1075 and 7075; magnesium AZ31B

1.	No. a-600 alundum (hard)	60 min.
2.	No. 38-900 (hard - sharp)	60 min.
3.	No. 38-1200 (hard - sharp)	60 min.
4.	Green rough (soft)	60 min.

Magnesium HK 31A

1.	No. 100 crystalon	30 min.
2.	No. 600 alundum	200 min.
3.	No. 38-900 A	90 min.
4.	No. 38-1200	120 min.

Titanium A-110-AT

1.	No. 100 crystolon	150 min.
2.	No. 600 alundum	180 min.
3.	No. 38-900A	150 min.

Titanium B-120-VAC

1.	No. 100 crystolon	300 min.
2.	No. 600 alundum	180 min.
3.	No. 38-900A	60 min.

Beryllium; QMV and 1% cu

1.	No. 100 crystalon	210 min.
2.	No. 600 alundum	40 min.
3.	No. 38-960A	270 min.
4.	No. 38-1200	60 min.

Surface roughness measurements were made with a profilometer on several specimens of both aluminum alloys and the AZ31B magnesium, and the roughness was found to be less than two microinches rms. The other alloys were polished to give the same appearance.

Since the electropolishing and anodizing processes altered the surface of the metals, fine scratches remaining after mechanically polishing were not visible in the finished specimens. Surface defects in unpolished or mill finished specimens were visible after anodizing, however.

Anodizing

The following anodizing processes were studies:

Aluminum - sulphuric acid, chromic acid, boric acid and hard coat

Magnesium - Dow No. 17 and HAE coatings

Titanium - sulfuric acid, sodium hydroxide, and a proprietary process

Beryllium - chromic acid, nitric acid, sodium hydroxide, and sulfuric acid

Both machine-polished and mill-finished (machined surfaces for beryllium) coupons were anodized by each process. The effect of electropolishing prior to anodizing was investigated. The anodizing procedures are presented below. Power was dc unless noted.

1. Aluminum 1075 and 7075

a. Pretreatment

Degrease in trichloroethylene

Clean in Oakite 61A (inhibited alkaline cleaner)
45 gm/L for 5 minutes at 93C

Cold water rinse

b. Electropolishing

Patented process, U. S. Patent No. 2338321

c. Anodizing

Sulfuric acid process

Solution: H_2SO_4 - 15% by weight

Temperature: 30°C

Applied potential, 15 vdc with lead cathode

Time: 30 minutes (standard)

Seal: 15 minutes in boiling water where noted.

Chromic acid process

Solution: CrO_3 - 7.5% by weight

Temperature: 35°C

Applied potential: start at low voltage and increase to 40 vdc and hold

Time: 30 minutes (standard)

Steel cathode

Hard Coat process

Solution: 15% H_2SO_4 saturated with CO_2

Temperature: -2°C

Current density: 25 amps/ft^2

Lead cathode

Time: 80 minutes (standard)

Seal: 15 minutes in boiling water where noted.

Boric acid process

Solution: 9% H_3BO_3, 0.2% $Na_2B_4O_7$

Temperature: 94°C

Applied potential: 230-250 vdc

Time: 15 minutes (standard)

Steel cathode

2. Magnesium AZ31B and HK31A

a. Pretreatment

Degrease in trichloroethylene

Dip in 180 gm/L CrO_3 at 93C

Clean in Oakite 61A 45 gm/L for 5 min. at 93C

Cold water rinse

b. Electropolishing

Solution: HCl-100ml; Ethylene glycol - 900 ml

Temperature: below 10 C

Time: 10 minutes

Current density: 20 amps/ft^2

c. Anodizing

HAE Process

Solution: The following chemicals were dissolved in the order given, then the bath was dummied with 1 ft^2 magnesium per gallon of solution.

KOH - 163 gm/L

Al (Metal) - 9.25 gm/L

Na_3PO_4-3.33 gm/L

$KMnO_4$ -18.3 gm/L

Temperature: 20 C

Current density: 20 amps/ft^2 ac

For thin tan coating terminate at 64 vac

For thick brown coating terminate at 85 vac

Dow 17 process

Solution: NH_4HF_2.- 237 gm/L

Na_2CR 207· 2H20-98 gm/L

H_3PO(85%)-85 ml/L

Heat half the water to 71C add NH_4HF_2 slowly. Add other ingredients and heat to 82 C.

Temperature: 71 C

Current density: 20 amps/ft^2 a-c

For thin green coating terminate at 64 vac

For thick green coating terminate at 90 vac

d. Post treatment

The coupons were rinsed in cold water.

3. Titanium A110AT and B120 VAC

a. Pretreatment

Degrease in trichloroethylene

Alkaline clean in Oakite 61A, 45 gm/L, 5 min. at 93 C

Pickle in solution of 40% by volume HF (5%) and 30% conc. HNO_3 at room temperature those coupons which were not electropolished.

Cold water rinse

b. Electropolishing

Solution: HF (50%) - 160 ml/L; CrO_3 - 500 gm/L

Temperature: 18 C

Current density: 325 amps/ft^2

Time: 10 minutes

Lead cathode

c. Anodizing

Sulfuric acid process

Solution: H_2SO_4 - 20% by weight

Temperature: 20 C

Applied voltage: 18 vdc

Time: 20 minutes

Lead cathode

Sodium hydroxide process

Solution: NaOH - 5% by weight

Temperature: 96C

Current density: 50 amps/ft^2

Time: 20 minutes

Mild steel cathode

Remarks: The B120 vac alloy did not anodize satisfactorily by this method.

Proprietary process

The anodizing procedure for titanium by a proprietary process was supplied by the project engineer.

d. Post Treatment

Coupons were rinsed in cold water, then sealed in boiling water 15 minutes.

4. Beryllium

a. Pretreatment

Degrease in trichloroethylene

Clean in Oakite 61A 45 gm/C 5 minutes at 93 C

Cold water rinse

b. Electropolishing

Identical to that used for aluminum (U. S. Pat. 2, 338, 321)

c. Anodizing

Chromic acid process

Solution: CrO_3 - 1% by weight
Temperature: 35C
Current density: 10 amps/ft^2

Time: 30 minutes

Graphite cathode

Nitric acid process

Solution: HNO_3 - 50% by volume
Temperature: 25 C
Current density: 30 amps/ft^2
Time: 30 minutes
Graphite cathode

Sodium hydroxide process

Solution: NaOH - 7. 5% by weight
Temperature: 25 C
Current density: 8 amps/ft^2
Time: 30 minutes
Mild steel cathode

Sulfuric acid process

Solution: H_2SO_4 - 1%

Temperature: 25 C

Current density: 10 amps/ft^3

Remarks: Anodized coating was rinsed off by the solution. These specimens not sealed.

d. Post treatments

Coupons were rinsed in cold water, then sealed in boiling water 15 minutes.

The anodizing solution variables on all of the coupons used for reflectance measurement are presented in Table 6. * Similar mill finish coupons were prepared at the same time for coating thickness measurements.

In the anodizing procedure for magnesium, the method of obtaining a light and a dark anodized coating is described. For the other alloys, coating thickness was varied by controlling the anodizing time. Standard/3, therefore, refers to an anodizing time equal to one-third of the time specified in the anodizing procedure. The Martin hard coat anodizing process, the proprietary process, and the patented electropolishing technique used on aluminum and beryllium were supplied by the project engineer.

The coupons were consecutively numbered as they were mechanically polished; therefore, the specimen number has no significance other than identification and location in the filing system.

Heat Treatment

It was desirable to investigate the effect of heat treatment on the reflectance of the specimens. Certain specimens were therefore heated both in air and under vacuum conditions.

* See Page 76 , Part II

The specimens to be heat treated in air were placed in a furnace heated to the proper temperature, held there for thirty minutes, and then removed. The aluminum and magnesium were heat treated at 800 F; the titanium and beryllium at 1500 F. The reflectance was then measured.

The temperature to which the specimens were heated in the vacuum chamber was limited by the vapor pressure of the material and other reasons as noted in discussion of results. After the reflectance measurements were made at elevated temperatures, in vacuum, a repeat measurement was made at room temperature to determine the extent of irreversible changes in the coatings.

ANODIZED COATING THICKNESS

Thickness of the anodized coating was determined for the aluminum, beryllium, and magnesium coupons by dissolving the coating and determining the weight change of the coupon. Using the handbook density for the oxide, the film thickness could then be calculated. This method, specified by the Project Engineer, is recommended by the American Society for Testing Materials (10).

A solution suitable for selectively dissolving the anodized coating on titanium could not be found. These coatings were, therefore, measured by sectioning the coupon and examining the cross section on a metallograph. The results of the measurements are presented in Table 5.

Coupons of anodized aluminum were also sectioned and measured on the metallograph to check the results obtained with the stripping and weighing technique This method was tried on magnesium; however, the coating was so soft that a sharp cross section could not be obtained. A comparison of coating thickness data for aluminum by both methods is given in Table 5.

TABLE 5

ANODIZED COATING THICKNESS

Material	Solution	Time	Electro-plated	Sealed	Spec. No	Thickness (cm)	Spec. No	Thickness (cm)	Assumed Oxide Density
					Al 7075		Al 1075		
Aluminum	Sulfuric	Std/3	yes	no	122	000231	94	.000231	3 99 gm/cm^3
	acid	Std	yes	yes	121	000554	96	.000711	"
	"	Std	yes	no	119	.000482	97	000635	"
	"	Std/3	yes	yes	123	.000231	102	.00033	"*
	"	Std/3	no	yes	124	.000221	103	.000254	"
	"	Std	no	no	125	.000635	104	.000584	"
	"	Std	no	yes	126	.000381	105	.000736	"
Aluminum	Chromic	Std	yes	no	109	.000239	91	.000163	"
	acid	Std/3	yes	no	112	.000022	93	000046	"
	"	Std/3	no	no	111	.000019	98	.000066	"
	"	Std	no	no	113	000016	99	.000145	"
Aluminum	Hard	Std	yes	yes	130	.00482	0	.0061	"
	coat	Std	yes	no	128	00559	106	.00508	"
	"	Std/3	yes	no	131	00140	107	00231	"
	"	Std/3	no	yes	133	00239	134	.00231	"
	"	Std	no	no	127	.00508	136	.00532	"
Aluminum	Boric	Std	yes	no	116	000028	M	.000043	"
	acid	Std	no	no	114	000038	101	.000038	"
	"	Std/3	yes	no	117	000028	135	.000033	"
					A731B		HK31A		
Magnesium	HAE	Light cast	no	no	148	000356	219	000597	3 65 gm/cm^3
	HAE	Dark	no	no	145	01922	216	.02584	"
	Dow 17	Light	no	no	146	.00027	217	.00496	"
	Dow 17	Dark	no	no	149	02639	218	.02152	"
					QMV		1% copper		
Beryllium	Chromic acid	Std	no	yes	172	000295	168	000719	3.02 gm/cm^3
	" "	Std/3	no	yes	---	---	170	000103	"
	Nitric acid	Std	no	yes	174	000927	167	000949	"
	" "	Std/3	no	yes	176	000613	---	---	"
	Sodium	Std	no	yes	173	000086	166	000106	"
	hydroxide	Std	yes	yes	177	000126	164	000159	"
					A 110 AT		B 120 VAC		
Titanium	Sulfuric	Std	no	yes	43	00004	207	00004	none
	acid	Std	yes	yes	38	00004	203	.00004	"
	"	Std	no	yes	45	00004	---	---	"
	"	Std	yes	yes	48	00004	---	---	"
	"	Std/3	yes	yes	178	00004	-	---	"
	Proprietary	Std	no	yes	41	00008	199	00011	"
	"	Std	yes	yes	---	---	201	00019	"
	"	Thin coat	yes	yes	37	00011	---	---	"
					Sectioning Method		Stripping Method		
A									
1075	Hard coat	Std	yes	yes	15	0089	0	0061	
"	"	Std/3	yes	no	20	0032	107	00231	
7075	Chromic acid	Std	yes	no	49	00019	109	000239	
"	"	Std/3	yes	no	51	00005	112	000022	
"	Boric acid	Std	yes	no	52	00010	116	000028	
1075	Chromic acid	Std	yes	no	55	00024	91	000163	
"	"	Std/3	yes	no	57	00010	93	000046	
"	Boric acid	Std	yes	no	59	00010	M	000043	
"	"	Std/3	yes	no	60	0008	135	000033	
7075		Std/3	yes	no	62	00005	117	000028	
"	[illegible]uric acid	Std	yes	yes	64	00012	121	000559	
"		Std/3	yes	no	66	00036	123	000231	
1075		Std/3	yes	no	[illegible]	00036	94	000231	
	"	Std	yes	yes	[illegible]	0011	[illegible]	000711	
7075	Hard coat	[illegible]	yes	yes	[illegible]	[illegible]	[illegible]	00482	
	"	[illegible]	yes	no	[illegible]	[illegible]	131	00140	

In most cases the thicknesses determined by the "stripping" technique was less than that by the "sectioning" method. Handbook density values for the metallic oxide were used to calculate thickness by the stripping method. Lower thickness values by this method, therefore, indicated that the anodized coatings had a lower density than the handbook values and probably were porous. The difference between the two measurements may, therefore, be used as an indication of the porosity of the anodized coatings.

RESULTS

The reflectance data are grouped according to alloy in Tables 7 through 31 and are presented graphically in Figures 23 through 186. Table 6 serve as an index to the curves.

The large number of variables made it impractical to attempt to measure all possible combinations of variables. Combinations of variables were therefore selected as shown in Tables 7 through 31 to give a good survey of the range of reflectance values that could be expected for each metal. For example, measurements were made at elevated temperatures for only one specimen of each alloy anodized by each specified process. The effect of elevated temperature on specimens measured only at room temperature can be estimated by comparing with changes produced in the similar specimen measured at elevated temperatures.

Several factors limited the maximum temperature at which measurements could be made. Chief among these was the vapor pressure of the metal. Any evaporation from the specimen would damage the hemisphere surface. Magnesium has a vapor pressure of 10^{-6} mm Hg at only 480° F. Measurements on magnesium were therefore limited to 350° F. Aluminum specimens softened and sagged and were severaly damaged somewhere between 900 and 1000° F. The maximum temperature for the aluminum was therefore held to 825° F.

At 1200° F and above the intensity of emitted radiation from the titanium and beryllium specimens with low reflectance was so high compared to the reflected energy that measurement accuracy became very poor. Beryllium temperatures were therefore limited to 1200° F and titanium to 1300° F. A method for eliminating the problem of poor accuracy due to emitted radiation with high specimen temperatures is discussed in the section, "Recommendations for Future Work". Time did not permit an investigation of this technique, however.

Rather severe outgassing from a titanium specimen was observed at about 1350° F and specimens heated to this temperature in vacuum or 1500° F in air showed marked changes in appearance. For these reasons 1300° F was considered a practical temperature limit for titanium.

As was expected, the reflectance of the specimens was strongly influenced by the oxide coating thickness. The boric acid process which produced a very thin coating on aluminum was almost transparent at all wavelengths. On the other hand, the hard coat process produced thick, hard oxide films with relatively low reflectance. It was observed that the hard coat films were crazed; punching the specimens from the anodized coupons and heating to elevated temperatures increased the crazing in these coatings.

The sulfuric acid process produced a very thin, transparent, deep-blue film on titanium. However, it was so fragile that it could be easily wiped off. The proprietary process produced an excellent coating, but it darkened appreciably at elevated temperatures. The sodium hydroxide process worked well on 110AT titanium, but produced no oxide coating at all on B120VAC. The sodium hydroxide anodized titanium specimen heated in air to 1500° F changed so greatly in appearance that it was considered unusable and was not measured.

Elevated temperatures appeared to produce two major effects. As would be expected, if water was present in the oxide film this was driven out at the higher temperatures as evidenced by the disappearance of the absorption

bands - especially at 3 microns. The second effect was a darkening or decrease in the reflectance of some coatings. This frequently had a greater effect in the short-wavelength region than in the long-wavelength region.

Absorptance or emittance values can be obtained by subtracting the reflectance values from unity. The ratio of solar absorptance to infrared emittance (α/ϵ) can then be estimated by comparing the average absorptance in the 0.4 to 1.6 micron region to the average emittance in the 7.0 to 20 micron region. An estimate of this type shows that α/ϵ for bare magnesium or boric acid anodized aluminum was about 2. The hard coat process gave a ratio of about 0.5, chromic acid about 0.4, and sulfuric acid about 0.3 on 1075 aluminum. The sulfuric acid process gave this low value with a relatively high infrared emittance. This would be an advantage on a spacecraft where there is appreciable internal heat generation (occupants, etc.) which must be radiated to space.

Since magnesium oxide has a very high reflectance in the visible region, one would expect anodized magnesium to have a low α/ϵ ratio. Just the reverse of this was found. Bare magnesium had an α/ϵ of about 7. The light Dow 17 process on AZ31B also had a ratio of about 7. The α/ϵ for the dark Dow 17 was reduced to about 0.7, however, due to the increase in the infrared emittance. Both solar absorptance and infrared emittance were higher with the HAE process and α/ϵ ranged from about 1 to 3.

The α/ϵ ratios for titanium were all high and varied from about 3.5 to 7. The sodium hydroxide process on 110 AT gave a solar absorptance of about 0.70 and an infrared emittance of about 0.10 making this an attractive combination for a solar collector.

Anodized beryllium was also found to have relatively high values of α/ϵ. The nitric acid process gave values for the ratio of about 1 and the sodium hydroxide process on beryllium plus 1% copper alloy gave a ratio of about 5.

The solar absorptance for this latter combination was about 0.92, however, indicating the blackness of its appearance. The extremely light weight of beryllium coupled with the high α/ϵ would make it attractive as a solar collector surface for space craft applications. Here toxicity of the beryllium oxide and high cost would not be serious disadvantages.

The type of anodizing process used was more significant than the effect of alloying elements in the substrate. In the case of magnesium for example, the HAE process produced tan or brown coatings on both alloys, whereas the Dow 17 process produced white or green coatings on both alloys depending on whether or not the process was carried to the dark condition. These differences extended into the infrared also.

It was necessary to wash specimens produced by a number of the processes in boiling water to remove traces of the anodizing solution. This had the effect of a hot water seal on those films subject to sealing and produced water absorption bands in the infrared spectrum. As mentioned previously, heating to elevated temperature removed this water and produced changes in the reflection values.

The effect of pretreatment was not consistant. In the case of thin coatings on aluminum - chromic acid and boric acid processes - electro-polishing increased the reflectance, particularly at the short wavelengths. There was no noticeable difference in the case of the sulfuric acid and hard coat processes. In the case of magnesium and particularly in the case of beryllium, electropolishing reduced the reflectance. The electropolished beryllium specimens had a thinner oxide film. In the case of titanium, electropolishing produced slightly higher reflectance with the sodium hydroxide process and slightly lower reflectance with the proprietary process. It appears that no generalization can be drawn regarding the effect of electropolishing prior to anodizing.

CONCLUSIONS

The results of this study indicate that the thermal radiation properties of the metals investigated can be varied over a wide range by the selection of the anodizing process and bath conditions. Aluminum anodized by the sulfuric acid process gave a low value of the solar absorptance, infrared emittance ratio and might be suitable for spacecraft applications if the surface were protected from high temperatures during the launch. On the other hand, sodium hydroxide anodized titanium might be considered for solar energy collectors due to its high value of α/ϵ.

The combination of elevated temperatures and high vacuum definitely removed water from those films which contained water and thus increased the reflectance at the wavelengths where water absorption band occurred. Decreases in reflectance especially in the short-wavelength region, were also observed in some heated specimens.

The effect of electropolishing prior to anodizing was not consistent In some cases it increased the reflectance and in some cases it decreased reflectance.

The integrating hemisphere reflectometer proved to be capable of measurements under a wider range of conditions than has hitherto been possible in a single apparatus. It is believed that further development can increase both the range, i. e., spectral range, resolution and permissible specimen temperature, and the precision of measurements with the device.

RECOMMENDATIONS FOR FUTURE WORK

The successful operation of the integrating hemisphere reflectometer depends on the characteristics of the diffusers. Both the reflectance and the diffuseness must be accurately known. It is suggested that a further search be made for better diffusers.

An alternate method which would eliminate the need for diffusers is recommended for consideration. This method involves locating the energy source at one of the conjugate foci. If a small black body could be constructed to operate at approximately 2500 F at 10^{-6} mm Hg, this could be then located at the conjugate focus. This would also eliminate any internal reflections and, therefore, reduce the effect of spherical aberrations.

The hemisphere was used as an approximation to an ellipsoid; however, spherical aberration did present a problem. An ellipsoid would greatly reduce or eliminate spherical aberration permitting the spectrometer slits to be varied to control energy, and give greatly increased spectral resolution.

At the higher specimen temperatures, the energy emitted by the specimen (especially low reflectance specimens) became an appreciable part of the total energy reaching the sensor. This signal at times became so large that the zero balance on the spectrometer could not balance out this signal. It is suggested that under these conditions the specimen itself could become the energy source.

When the specimen is heated to a given temperature it becomes an energy source. The specimens and diffuser positions could then be interchanged so that the sensor receives energy reflected from the diffuser. If the energy reaching the sensor is then added up for an infinite number of internal reflections, the sum of the series will be:

$$G_1 = \frac{W_\lambda \rho_h \rho_{d_1} \; D\,F}{\left[1 - \rho_h^2 \rho_s \rho_{d_1} \; D\right]} \tag{32}$$

If the first diffuser is now replaced by a second diffuser with a different reflectance, a reference measurement can be obtained. The two equations can then be solved for the specimen reflectance

$$\rho_s = \frac{\rho_{d_1} - \frac{G_1}{G_2} \rho_{d_2}}{\rho_h^2 \rho_{d_1} \rho_{d_2} \left(1 - \frac{G_1}{G_2}\right)} \tag{33}$$

This technique would provide a means of making measurements at high specimen temperatures where the emitted energy level is high compared with the reflected energy in the present schemes. Some research would be required, however, to find a pair of suitable diffusers.

The authors believe that this technique offers interesting possibilities and recommend a further investigation of the method.

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7. Handbook of Chemistry and Physics, 38th ED., Chemical Rubber Publishing Co.

8. Agnew and Mc stan, "Experiments Concerning Infrared Diffuse Reflectance Standards in the Range 0.38 to 20.0 microns", J. of Opt. Soc. of Am, V. 43, N. 11, 1953, p. 999.

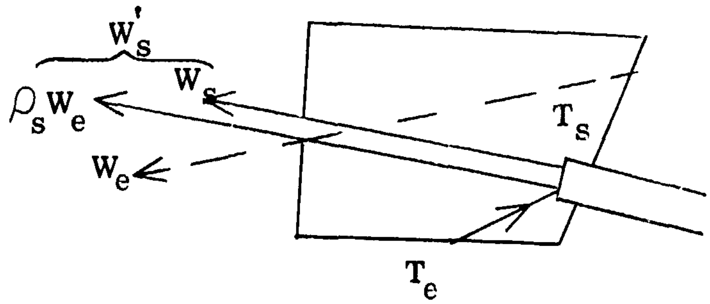
9. Betz, Olson, Schurin, and Morris, "Determination of Emissivity and Reflectivity Data on Aircraft Structural Materials", WADC Tech. Report 56-222, Part II, 1957, p. 12.

10. American Society for Testing Materials, Vol. 40, 1940, Philadelphia, Pa.

APPENDIX TO PART I

THEORY OF BLACK BODY REFLECTOMETER

The sketch below shows schematically the source of the radiant energies of interest.



The energy, W_s' , from the specimen consists of emitted energy, W_s, plus reflected energy, $\rho_s W_e$. The energy incident on the specimen is the environment radiation, W_e, from the hohlraum.

The environmental radiation at any wavelength is given by Planck's equation:

$$W_e = \frac{C_1}{\lambda^5 \left(e^{C_2/\lambda T_e} - 1\right)} = \frac{C_1}{\lambda^5 (x_e - 1)} \qquad (34)$$

where C_1 - Planck's first constant

λ = wavelength

C_2 = Planck's second constant

T = absolute temperature

Subscript e refers to environment

Similarly the energy emitted by a specimen with a spectral emittance ϵ_s is:

$$W_s = \frac{\epsilon_{\lambda s} C_1}{\lambda^5 (e^{C_2/\lambda T_s} - 1} = \frac{\epsilon_{\lambda s} C_1}{\lambda^5 (x_s - 1)} \tag{35}$$

A third measurement of a black body at a temperature, T_b, different from the hohlraum temperature, T_e, is required. This energy is given by

$$W_b = \frac{C_1}{\lambda^5 (e^{C_2/\lambda T_b} - 1)} = \frac{C_1}{\lambda^5 (x_b - 1)} \tag{36}$$

Making use of the relationship $\rho_s = 1 - \epsilon_s$, the total energy from the specimen is:

$$W_s' = \rho_{\lambda_s} \frac{C_1}{\lambda 5} \left[\frac{1}{x_e - 1} - \frac{1}{x_s - 1} \right] + \frac{1}{x_s - 1} \tag{37}$$

Subtracting equation (36) from (34) and (35) and combining these equations gives the following expression for $\rho_{\lambda s}$:

$$\rho_{\lambda_s} = \left[\frac{W_s' - W_b}{W_e - W_b} \right] \left[\frac{\frac{1}{(x_e - 1)} - \frac{1}{(x_b - 1)}}{\frac{1}{(x_e - 1)} - \frac{1}{(x_s - 1)}} \right] - \left[\frac{\frac{1}{(x_s - 1)} - \frac{1}{(x_b - 1)}}{\frac{1}{(x_e - 1)} - \frac{-1}{(x_b - 1)}} \right] \tag{38}$$

If the reference black body measurement is made with the temperature equal to the specimen temperature,

$$T_b = T_s \quad \text{and} \quad x_b = x_s \tag{39}$$

then

$$\rho_{\lambda_s} = \frac{W_s - W_b}{W_e - W_b} \tag{40}$$

Also if the specimen temperature is low compared with the environmental temperature,

$$T_s << T_e \tag{41}$$

the energy radiated by the black body at the specimen temperature will be small and can be neglected. Then

$$\rho_{\lambda_s} = \frac{W_s'}{W_e} \tag{42}$$

This is the equation commonly used with the black body reflectometer. Care must be exercised in the use of this equation to make certain that the energy emitted by the specimen can be ignored. Equation (40) was used to estimate the errors in this assumption when using heated specimens and it was found that the effect of specimen emission could not be ignored. Equation (40) was, therefore, proposed for use with the black body reflectometer.

PART II

PRESENTATION OF REFLECTANCE DATA

CODE FOR DATA:

- MF - Mill Finish
- MP - Mechanically Polished
- EP - Electropolished
- Std - Standard Anodizing Time
- RT - Room Temperature
- RT_f - Room Temperature after heating in vacuum
- HT - Heat Treated in air at specified temperature for 30 minutes

INDEXING OF SPECIMEN DATA:

The spectral reflectance data presented in Figures 23-186 are arrayed in the same sequence as the data presented in Tables 7-31

TABLE 6

INDEX OF SPECIMEN VARIABLES

Aluminum

Specimen Preparation					No. of Specimen Measured									
Pre-	Anodizing			Heat	Alloy 1075					Alloy 7075				
Treatment	Bath	Time	Sealed	Treat	RT	300F	600 F	825 F	RT_f	RT	300F	600 F	825 F	RT_f
MP, EP	none			no	16									
MP, EP	Chromic	std	no	no	55	55	55	55	55	50		50		50
MP, EP	acid	std	no	800	56									
MP, EP	"	std/3	no	no	57					51				
MP	"	std/3	no	no	33					75				
MP	"	std	no	no	84									
MP, EP	"	std	no	no	92					110				
MP, EP	Sulfuric	std	yes	no						63	63	63	63	63
MP, EP	acid	std	yes	no	69		69		69	64				
MP, EP	"	std	no	no						65				
MP, EP	"	std/3	no	no	67					66				
MP, EP	"	std	yes	800	68									
MP, EP	"	std/3	yes	no	71	71				73				
MP, EP	"	std/3	yes	no	72					74				
MP	"	std	no	no	80					77				
MP	"	std	yes	no	81					78				
MP, EP	"	std	yes	no						120				
MP, EP	Hard	std	no	no	13					86				
MP, EP	coat	std	yes	no	15		15		15	87	87	87	87	87
MP, EP	"	std	yes	800						88				
MP, EP	"	std/3	no	no	20					89				
MP	"	std/3	yes	no	23					11				
MP	"	std	no	no	82					85				
MP, EP	"	std	yes	no	500					129				
MP, EP	Boric	std	no	no						52	52	52	52	52
MP, EP	acid	std	no	800	58									
MP, EP	"	std	no	no	59	59	59	59	59					
MP	"	std	no	no	79					54				
MP, EP	"	std/3	no	no	60					62				
MP, EP	"	std	no	no	100					115				

TABLE 6 (continued)

Magnesium

Specimen Preparation					No. of Specimen Measured					
Pre-	Anodizing			Heat	Alloy AZ31B			Alloy HK31A		
Treatment	Bath	Time	Sealed	Treat	RT	350 F	RT_f	RT	350 F	RT_f
MP	none		no	no	156					
MP, EP	HAE	light	no	no	25	25	25	215		
MP, EP	"	"	no	no	36					
MP, EP	"	"	no	800	25					
MP	"	"	no	no	138			211	211	211
MP	"	"	no	800				211		
MP	"	"	no	no	138					
MP, EP	HAE	dark	no	no	155					
MP	"	"	no	no	140			210		
MP	"	"	no	800	140					
MP	"	"	no	no	140					
MP, EP	Dow17	light	no	no	31	31	31	214	214	214
MP, EP	"	"	no	800				214		
MP	"	"	no	no	152			212		
MP	"	"	no	no	152					
MP, EP	Dow17	dark	no	no	35	35	35			
MP, EP	"	"	no	800	35					
MP	"	"	no	no	158			213		

TABLE 6 (continued)

Beryllium

Pre-Treatment	Specimen Preparation: Anodizing Bath	Anodizing Time	Sealed	Heat Treat	No. of Specimen Measured: QMV Alloy RT	QMV Alloy 400 F	QMV Alloy 800 F	QMV Alloy 1200 F	QMV Alloy RT_f	1% Copper Alloy RT	1% Copper Alloy 400 F	1% Copper Alloy 800 F	1% Copper Alloy 1200 F	1% Copper Alloy RT_f
MF	none		no	no	171									
MF	Sulfuric acid	std	yes	no						162				
MF EF	Sodium	std	yes	no	177					164				
MF EF	Hydroxide	std	yes	1500	177									
MF	"	std	yes	no	173	173	173	173	173	166	166	166	166	166
MF	Nitric	std	yes	no	174					167				
MF	acid	std/3	yes	no	176									
MF	Chromic	std	yes	no	172					168				
MF	acid	std/3	yes	no						170				

Titanium

Pre-Treatment	Specimen Preparation: Anodizing Bath	Anodizing Time	Sealed	Heat Treat	No. of Specimen Measured: Alloy 110 AT RT	Alloy 110 AT 500 F	Alloy 110 AT 1000 F	Alloy 110 AT 1300 F	Alloy 110 AT RT_f	Alloy B120 VAC RT	Alloy B120 VAC 500 F	Alloy B120 VAC 1000 F	Alloy B120 VAC 1300 F	Alloy B120 VAC RT_f
MF EF	none		no	no	46					202				
MF	none		no	no	209									
MF EF	Sulfuric	std	yes	no	38					203				
MF	acid	std	yes	no						207				
MF, Pickled	"	std	yes	no	43									
EF	Sodium	std	yes	no	48	48	48	48	48					
MF Pickled	Hydroxide	std	yes	no	45	45*	45**	45***	45					
MF EF	"	std/3	yes	no	178									
MF	Proprietary	std	yes	no	41					199				
MF EF	"	std	yes	no	47	47	47	47	47	201	201	201		201
MF EF	"	thin coat	yes	no	37					197				
MF EF	"	std	yes	1500						201				

*300°F **600°F ***900°F

TABLE 7

SPECTRAL REFLECTANCE OF 7075 ALUMINUM ANODIZED IN CHROMIC ACID

Specimen No.	50	50	50	51	75	110
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP	MF, EP
Anodizing Time	Std	Std	Std	Std/3	Std/3	Std
Post Treatment	None	None	None	None	None	None
Spec. Temp.	RT	600°F	RT_f	RT	RT	RT
Wavelength Microns						
.4	.426		392	500	.303	
.45	.448	.387	424		352	
.5	.464	.401	431	.561	.383	.545
.6	.523	446	[illegible]	.559	.397	.601
.7	.517	.454	487	.560	368	650
.8	.519	.495	[illegible]	.554	.309	617
.9	.592	510	579	617	.449	646
1.0	644	.576	[illegible]	645	497	764
1.2	723	690	730	809	570	822
1 4	772	705	756	822	606	839
1.6	784	713	769	840	573	857
1 8	789	.724	.771	983	597	861
2 0	798	738	771	870	555	[illegible]
2 5	804	777	807	903	647	886
3 0	807	[illegible]	873	922	.676	918
3 5	.832	855	891	943	708	933
4	854	875	907	959	721	966
5	872	895	931	963	745	962
6	870	913	951	[illegible]	712	965
7	888	[illegible]	950	[illegible]	776	981
8	895	938	946	[illegible]	792	[illegible]
9	885	936	[illegible]	[illegible]	791	979
10	870	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	844	929	[illegible]	[illegible]	[illegible]	958
12	[illegible]	[illegible]	[illegible]	[illegible]	758	979
13	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
14	[illegible]	[illegible]	[illegible]	[illegible]	778	[illegible]
15	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
16	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
17	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 8

SPECTRAL REFLECTANCE OF 1075 ALUMINUM IN CHROMIC ACID

Specimen No.	55	55	55	55	55	56	57	83	84	92
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP	MP	MF, EP
Anodizing Time	Std	Std	Std	Std	Std	Std	Std/3	Std/3	Std	Std
Post Treatment	None	None	None	None	None	HT 800°F	None	None	None	None
Spec. Temp	RT	300° F	600°F	825°F	RT_f	RT	RT	RT	RT	RT
Wavelength, Microns										
.4		.685			.561			550	.477	.78P
.45	.718	.707	.680	.659	.619	.736	.840			
.5	.740	.731	.749	.688	650	.770	.906	.533	.566	.784
.6	.734	.788	.770	.752	.706	.817	.841	.541	.582	.885
.7	.730	.740	.766	.728	.674	.819	956	.547	.574	.784
.8	.725	.799	.770	.931	.676	.770	.942	.548	.533	.813
.9	.764	.770	.784	.774	.723	.802	1025	.563	.595	.824
1.0	.832	.823	.806	.780	.819	.896	1.031	.582	.744	894
1.2	.874	.884	890	826	838	.916	.904	.678	.896	925
1.4	.895	.873	.861	.842	.871	.938	.952	.752	.823	.927
1.6	.895	.896	.886	.856	883	959	.976	.882	.828	952
1.8	.909	.908	.894	.870	.893	.968	.984	.836	.847	957
2.0	.926	.918	.906	885	.900	.974	1.069	.826	.840	963
2.5	.930	.927	.918	.897	.918	981	.997	.836	864	972
3.0	.928	923	.928	.899	.922	.947	976	903	839	.947
3.5		.937	.936	911	941	966	975	922	883	.976
4	.959	.947	.940	920	.948	981	.978	941	917	982
5	953	938	.944	902	.933	971	.989	938	913	971
6	.967	950	.934	926	950	97	1 025	933	.932	982
7	941	.931	.904	897	952	956	1 001	953	921	958
8	906	.895	865	843	894	907	985	980	861	915
9	.810	.803	787	752	.770	801	983	960		818
10	.641	618	629	604	625	625	950	893	678	643
11	439	465	495	515	461	439	938	[illegible]		426
12	343	362	427	471	383	398	959	[illegible]	411	364
13	.332	.340	362	612	321	342	959	806	380	366
14	280	307	332	316	278	293	965	793	348	389
15	270	270	278	287	256	290	954	783	226	308
16	228	264	182	376	173	266	964	808	165	212
17	187	182		304	217	238	987	812	158	236
18	191	215		129	153		982	[illegible]	242	[illegible]
19	086	175			[illegible]		[illegible]	[illegible]	[illegible]	
20		137			[illegible]		[illegible]	[illegible]	[illegible]	
[illegible]							[illegible]			
[illegible]										

TABLE 9

SPECTRAL REFLECTANCE OF 7075 ALUMINUM ANODIZED IN SULFURIC ACID

Specimen No	63	63	63	63	63	64	65	66
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP
Anodizing Time	Std	Std	Std	Std	Std	Std	Std	Std/3
Post Treatment	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed	None	None
Spec. Temp.	RT	300°F	600°F	825°F	RT_f	RT	RT	RT
Wavelength Microns								
4			.453	332	.309		495	548
45	499	533	477	395	311	553	512	585
.5	532	.556	514	.417	334	611	567	635
6	575	584	521	454	367	656	617	671
7	.623	573	.523	476	367	658	613	683
8	.637	583	.581	.464	.418	.639	.585	.658
9	637	632	573	548	458	675	632	687
1.0	741	652	595	557	512	804	778	705
1.2	751	689	643	607	582	813	800	.853
1 4	778	720	663	.596	607	827	828	.881
1 6	804	758	684	615	627	850	847	898
1 8	828	755	703	631	638	851	.851	908
2 0	853	801	714	641	657	851	867	922
2 5	799	725	732	689	641	786	857	987
3 0	225	574	718	690	554	217	585	814
3 5	430	689	764	734	620	426	705	889
4	565	743	760	723	677	576	788	916
5	67	784	764	724	743	676	842	940
6	72	777	785	735	730	644	738	881
7	623	673	594	601	699	622	765	886
8	149	056	164	419	419	141	118	450
9	059	022		4.7	385	015	047	283
10	064	014		347	334	070	107	269
11		056	159	[illegible]	406	094	097	100
12				430	427	132	193	173
13	11[illegible]	131	[illegible]	[illegible]	473	160	173	[illegible]
14				[illegible]	[illegible]	[illegible]	506	179
15	20[illegible]	211		[illegible]	[illegible]	[illegible]	242	[illegible]
16				[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]			[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

TABLE 9 (Continued)

Specimen No	73	74	[illegible]	7[illegible]	120
Pretreatment	MP, EP	MP	MP	MP	MP, EP
Anodizing Time	Std 3	Std 3	Std	Std	Std
Post Treatment	Sealed	Sealed	None	Sealed	Sealed
Spec. Temp	RT	RT	RT	RT	RT
Wavelength Microns					
40	[illegible]				
45	638	607		434	591
5	677	639	[illegible]	519	653
6	703	679	547	565	676
7	692	668	5[illegible]7	626	694
8	694	660	[illegible]13	578	717
9	754	733	6[illegible]3	653	769
10	788	770	[illegible]	722	826
12	[illegible]	808	743	762	[illegible]
14	848	836	[illegible]	805	953
16	863	863	[illegible]	819	[illegible]
18	[illegible]	883	811	[illegible]	[illegible]
20	884	[illegible]	847	811	[illegible]
[illegible]	[illegible]	886	821	739	[illegible]
30	619	[illegible]	[illegible]	401	[illegible]
[illegible]	736	764	[illegible]	50[illegible]	[illegible]
[illegible]	[illegible]	811	700	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	041	[illegible]	[illegible]
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]				[illegible]

TABLE 10

SPECTRAL REFLECTANCE OF 1075 ALUMINUM ANODIZED IN SULFURIC ACID

Specimen No.	67	68	69	69	69	71	71	72	80	81
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP	MP	MP
Anodizing Time	Std/3	Std	Std	Std	Std	Std/3	Std/3	Std/3	Std	Std
Post Treatment	None	Std. HT 800°F	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed	None	Sealed
Spec. Temp.	RT	RT	RT	600°F	RT_f	RT	300°F	RT	RT	RT
Wavelength Microns										
.4	.980	.704		732	.646	.852	.861	.503		
.45		.705	.736	.725	.701			.460	.712	.981
.5	.977	.715	.764	745	.721	896	.679	.497	.720	.786
.6	.751	.709	.761	.746	.723	.608	903	499	722	.779
.7	.957	.701	.739	.747	.711	.862	.859	.480	.706	.760
.8	.949	.738	.727	.741	.717	876	.845	.721	.705	.760
.9	.970	.700	.732	.753	734	.911	.928	.529	734	766
1.0	.957	.773	.833	.764	769	898	.945	.564	.775	815
1.2	.962	.818	.849	807	.83[illegible]		907	.670	817	860
1.4	.960	.834	.848	.837	852	944	899	.667	849	874
1.6	.975	.833	862	.847	861	.947	.911	.699	856	873
1.8	.938	.845	.863	.857	.874	969	.932	.723	851	910
2.0	.976	.849	.843	.861	.859	.954	.931	.754	.904	903
2.5	.988	.823	.773	.843	.819		.937	.746	.863	839
3.0	.910	.448	.284	.828	561	696	.900	572	.737	285
3.5	.951	.658	340	.872	702		.916	.766	.927	.582
4	.966	.745	.666	.878	.776	.897	.930	.893	886	720
5	.981	822	.737	884	854	921	.926	.920	914	819
6	.891	.776	.724	.840	806	[illegible]	.921	855	.896	.762
7	900	.724	.649	.778	732		1.032	994	.829	794
8	.444	.038	.032	.041	.046	187	22[illegible]	408	020	143
9	283	.068	.046	.037	054		.062	203	045	032
10	.242	.063	.039	055	[illegible]	224	.249	217	035	067
11	.141	.106	089	143	129	160	308	121	.203	.114
12	.240	215			734	.258	287	.106	244	219
13	.294	.272	.229	370	.275	294	.275	232	280	
14	.299	235			306	352	.382	.304	347	.352
15	.354	.313	315	396	328	390	375	.336	365	
16	394	.330			326	363	458	363	.393	394
17	.393	.298	316	382	.374	349	422	379	413	
18	386	282			357	383	372	398	395	416
19	347	359	.276	429	332	431	523	435	434	
20		.325			304	.349		384	432	473
21		342	.432		379			.371		
22					536					

TABLE 11

SPECTRAL REFLECTANCE OF 7075 ALUMINUM HARD COAT ANODIZED

Specimen No	11	85	86	87	87	87	87	87	88	89	129
Pretreatment	MP	MP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP
Anodizing Time	Std/3	Std	Std	Std	Std	Std	Std	Std	Std	Std/3	Std
Post Treatment	Sealed	None	None	Sealed	Sealed	Sealed	Sealed	Sealed	Std, HT-800°F	None	Sealed
Spec Temp	RT	RT	RT	RT	300°F	600°F	825°F	RT_f	RT	RT	RT
Wavelength Microns											
4	.099								203		193
45	111	172	160	163	144	070	065	079	210	211	184
5	120	160	161	155	150	070	068	075	214	245	183
6	137	147	149	159	149	071	068	074	214	303	175
7	159	141	135	153	150	076	071	077	202	332	170
8	218	164	120	162	200	135	091	135	243	395	
9	245	141	125	190	188	123	122	141	240	452	202
1 0	280	156	142	229	217	163	153	159	286	516	235
1 2	362	203	196	300	296	253	245	252	356	625	285
1 4	441	253	250	364	347	330	314	318	407	668	335
1 6	465	290	284	400	389	373	361	369	423	699	362
1 8	498	326	319	426	420	415	399	411	454	728	379
2 0	536	347	335	549	445	450	408	447	480	752	387
2 5	465	311	293	479	402	445		473	411	707	309
3 0	[illegible]	082	074	138	169	351		426	104	450	078
3 5	133	108	096	127	282	422		497	135	588	064
4 0	[illegible]	162	146	182	368	435		535	206	682	081
5	317	183	247	301	437	439		542	344	755	140
6	229	145	134	208	313	068		399	205	662	090
7	178	085	067	124	137	037		114	114	500	070
8	035	022	017	040	125			015	018	026	023
9	059	048	048	084	135			028	027	050	058
10	055	033	035	041	135			022	035	043	033
11	081	098	095	107	170			092	087	126	116
12	265	195	[illegible]	174	207			192		223	183
13	270		216	220	260			216	283	215	234
14	289	268	256	258	292			245		299	289
15	290		279	292	258			273	270	299	288
16	352	317	284	309	236			290		345	309
17	347		302	349	267			305	300	352	335
18	355	302	321	328	250			286		358	295
19	399		31[illegible]	362	415			379		394	333
20	435	285	263	367				270		334	280
21											
22											

TABLE 12

SPECTRAL REFLECTANCE OF 1075 ALUMINUM HARD COAT ANODIZED

Specimen No	13	15	15	15	20	23	8	500
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP	MP	MP, EP
Anodizing Time	Std	Std	Std	Std	Std/3	Std/3	Std	Std
Post Treatment	None	Sealed	Sealed	Sealed	None	Sealed	None	Sealed
Spec. Temp	RT	RT	600° F	RT	RT	RT	RT	RT
Wavelength Microns								
4		190	310	381	345	446		236
45	214	242	403	436	421	485	199	289
5	265	292	448	462	.459	511	229	332
6	319	342	483	500	507	542	276	379
7	.341	366	503	.511	514	551	295	404
8	328	389	497	492	541	624	194	443
9	433	442	.584	575	577	.598	368	480
1 0	.460	494	584	617	635	691	375	511
1 2	499	562	625	642	677	745	462	580
1 4	562	59[illegible]	682	661	706	757	506	603
1 6	594	618	670	679	732	775	544	601
1 8	615	639	696	690	730	793	576	644
2 0	610	645	.709	707	773	816	603	63[illegible]
2 5	576	539	628	611	696	752	554	[illegible]
3 0	208	115	298	324	415	301	237	119
3 5	323	131	571	508	611	483	394	113
4 0	450	203	547	572	686	617	486	174
5	561	310	580	600	735	724	585	274
6	351	196	342	412	612	639	409	177
7	112	077	162	104	327	442	137	074
8	022	026	175	033	024	046	029	023
9	052	071		058	018	039	018	056
10	0[illegible]6	049	215	035	032	052	058	026
11	093	100		116	063	193	126	067
12	219	251	232	238	128	255	254	219
13	317	307	276	294	[illegible]	[illegible]		295
14	336	343		298	220	37[illegible]	354	339
15	330	386	474	283	253	385		342
16	356	379		314	261	376	356	372
17	366	3[illegible]	408	269	274	361		3[illegible]
18	409	40[illegible]		[illegible]	270	[illegible]	399	[illegible]
19	328	384		296	[illegible]			[illegible]
20	41[illegible]	[illegible]		[illegible]	[illegible]		[illegible]	[illegible]
21	34[illegible]	[illegible]			35[illegible]			[illegible]
22	4[illegible]							

[illegible]

TABLE 13

SPECTRAL REFLECTANCE OF 7075 ALUMINUM ANODIZED IN BORIC ACID

Specimen No.	52	52	52	52	52	54	62	115
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP,	MP, EP	MF, EP
Anodizing Time	Std	Std	Std	Std	Std	Std	Std/3	Std
Post Treatment	None	None	None	None	None	None	None	None
Spec. Temp.	RT	300°F	600°F	825°F	RT_f	RT	RT	RT
Wavelength Microns								
.4	492	.599	.509	.139	.428			495
.45	.521	.542	.550	.487	.450	.638	.660	.481
.5	.596	.587	.577	.543	.513	.601	.620	.538
.6	530	.510	.475	.455	.421	.701	.744	.501
.7	.579	637	.557	.562	.510	.735	.763	.533
.8	[illegible]	665	.587	.643	.574	.636	.739	.538
.9	.621	.656	.605	.627	.539	.692	.709	.621
1.0	.645	.679	.597	.622	.550	.815	.809	.595
1.2	.753	.768	.735	748	.710	793	.889	.767
1.4	.796	.810	.788	.803	.737	.89[illegible]	.912	.788
1.6	.793	.812	.793	.805	.748	.891	.901	.805
1.8	.803	.840	.793	.792	.771	.891	.902	.812
2.0	.807	.837	.794	.780	759	.901	.904	.810
2.5	801	.829	.708	.776	.760	.905	.910	.809
3.0	.775	.819	.799	.785	.784	.909	.903	.790
3.5	.807	.836	.813	.819	.806	.949	.932	.813
4.0	.825	.848	.832	.830	.821	961	.948	.852
5	.852	.867	848	.833	.859	.979	.964	.880
6	857	874	.867	853	.872	.986	.981	888
7	828	.846	837	.836	851	975	.963	.875
8	.836	856	850	.841	.858	982	.973	.886
9	.846	.871	.864	.867	.874	.985	.976	.907
10	.831	.847	852	861	.864	971	.968	897
11	821	.836	838	832	.856	.947	938	.914
12	808	.830	824	816	849	954	949	.919
13	.811	.823	.829	819	842	970	.987	.913
14	.821	83[illegible]	826	846	.839	.979	976	.909
15	825	.828	.845	842	847	.984	982	922
16	.827	.833	837	855	855	.988	996	.928
17	.814	858	860	82[illegible]	856	1 000	992	927
18	835	855	878	847	.857	1 015	996	925
19	825	87[illegible]	.881	855	888	1 020	1 007	.92[illegible]
20	867	896	915	880	862	1 012	1 074	904
21	.883	919	912	881	874	1 041	1 025	931
22	766	88[illegible]	893	853	791	1 054	966	1 017

TABLE 14

SPECTRAL REFLECTANCE OF 1075 ALUMINUM ANODIZED IN BORIC ACID

Specimen No.	50	59	59	59	59	59	60	79	100
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP	MP, EP
Anodizing Time	Std	Std	Std	Std	Std	Std	Std/3	Std	Std
Post Treatment	HT 800°F	None	None	None	None	None	None	None	None
Spec. Temp.	RT	RT	300°F	600°F	825°F	RT_f	RT	RT	RT
Wavelength Microns									
.4	.655	.700	.853	.857	.839	.676		.429	.644
.45	.673	.668	.783	.779	.787	.657		.446	.645
.5	.687	.718	.837	.839	.845	.706	.873	.444	.681
.6	.637	.650	.792	.780	.764	.665	.842	.439	.644
.7	.650	.657	.797	.804	.804	.662	.878	.415	.627
.8	.680	.817	.748	.837	.821	.706	.794	.558	.676
.9	.643	.741	.765	.756	.763	.685	.759	.396	.672
1.0	.724	.688	.792	.767	.759	.691	.857	.470	.687
1.2	.806	.817	878	.884	.865	.787	.891	.528	.793
1.4	.831	.823	.915	.910	.892	.827	.935	.610	.848
1.6	.835	.820	.928	.915	.906	.834	.932	.654	.870
1.8	.837	.837	.934	.907	.899	.831	.935	.674	.856
2.0	.840	.834	.927	.924	.908	.815	.933	.661	.854
2.5	.899	.827	.939	.922	.907	.814	.931	.673	.850
3.0	.848	.823	.950	.933	.914	.813	.933	.655	.843
3.5	.870	.836	.957	.947	.940	.835	.954	.682	.863
4.0	.889	.858	.967	.958	.944	.855	.972	.708	.890
5	.917	.880	.979	.968	.958	872	.985	.770	911
6	.925	.874	.982	.980	.984	.874	.993	.788	.923
7	.926	.878	.962	.973	.970	.870	.981	.791	.922
8	.932	.886	.988	.980	969	.876	.986	.805	925
9	.936	.882	.988	.982	.973	.873	.938	.807	.926
10	.914	.853	966	.963	.958	843	.961	.788	.903
11	.909	.826	.931	.951	957	828	.948	746	.907
12	.921	.853	.976	954	951	.838	.959	.756	.929
13	.921	.842	962	.985	975	.846	.977	.733	922
14	.926	.844	.976	983	984	846	986	.770	923
15	.932	.862	958	.993	993	853	970	787	921
16	.943	863	984	995	997	864	997	801	924
17	.948	864	995	1 006	1 009	853	1.007	.810	935
18	940	870	1 005	1 026	1 020	876	1 017	817	943
19	.950	893	999	1 017	1 025	876	1 027	829	941
20	945	912	999	1 027	1 025	840	1 026	741	935
21	953	912	558	1 026	1 016	875	1 001	760	960
22		706	1 054	1 025	1 038	853			

TABLE 15

SPECTRAL REFLECTANCE OF AZ31B MAGNESIUM ANODIZED IN HAE

Specimen No.	25	25	25	25	36	138	138	140	140	140	155
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP	MF	MP	MP	MF	MP, EP
Anodizing Coating	Light	Light	Light	Light	Light	Light	Light	Dark	Dark	Dark	Dark
Post Treatment	None	None	HT 800°F	None	None	None	None	None	HT 800°F	None	None
Spec. Temp.	RT	350°F	RT	RT_I	RT	RT	RT	RT	RT	RT	RT
Wavelength Microns											
.4	.229	.265	.168	.209	.241	.282	.279	.061	.076	072	.072
.45	.256	.277	.175	.282	.302	.298	.286	.073	.082	.076	.072
.5	.308	.304	.190	.309	.334	.346	.378	.077	.083	078	.071
.6	.398	.377	.227	.381	.424	.304	.420	.090	.092	096	.105
.7	.433	.424	.260	.425	.475	264	467	.111	.087	109	.132
.8	.549	.484	.408	.406	.453	.514	.494	134	.169	.275	166
.9	.530	.525	.350	.510	.552	.566	539	.157	.147	1 025	181
1.0	.554	.546	.383	.554	.569	.582	.556	.171	.158	.176	.219
1.2	.553	.556	.449	.541	.560	.585	.582	205	.202	.216	.271
1.4	.569	.555	.468	.553	576	.590	.581	235	.228	.235	.301
1.6	.565	.570	.480	568	.568	.584	.573	.265	.259	.256	.327
1.8	.553	.568	.484	.544	.556	.593	571	.275	281	.276	.346
2.0	.559	.580	.497	668	570	.621	.590	.303	.299	.296	360
2.5	616	.628	.569	618	.659	707	.687	325	.339	322	401
3.0	.647	697	.651	701	739	774	.746	.289	356	296	.371
3.5	.721	.761	.737	.773	800	.831	.808	.386	.437	382	.445
4	.781	.798	786	820	.840	861	842	.457	.491	455	553
5	.865	.854	.861	875	893	.903	.880	522	.547	519	630
6	.858	.848	.880	867	.905	911	.894	.521	.587	523	642
7	827	.818	848	.839	.904	934	.900	338	377	330	.484
8	.886	.871	885	.893	.917	.925	907	313	.351	294	514
9	.660	.681	654	.679	743	756	742	.035	036	044	036
10	.663	647	686	.695	764	793	779	046	027	047	052
11	790	.771	806	795	858	.891	846	084	066	092	165
12	.781	.763	.796	788	843	911	885	052		060	085
13	.695	.647	707	678	778	878	856	035	051	067	068
14	743	702	718	719	801	876	858	161		.203	264
15	713	691	700	751	786	866	861	376	254	.323	403
16	.710	594	667	723	796	861	844	372	.401	394	363
17	760	679	738	730	790	896	841	427	519	424	436
18	740	[illegible]	802	800	807	848	849	515	530	513	526
19	.778	617	736	819	794	907	852	374	529	466	557
20	737	801	782	710	795	910	881	371	623	400	576
21				198	785			569		387	
22				860	743			576		414	

TABLE 16

SPECTRAL REFLECTANCE OF HK31A MAGNESIUM ANODIZED IN HAE

Specimen No.	210	211	211	211	211	215
Pretreatment	MP	MP	MP	MP	MP	MP, EP
Anodizing Coating	Dark	Light	Light	Light	Light	Light
Post Treatment	None	None	None	None	HT 800°F	None
Spec. Temp.	RT	RT	350°F	RT_f	RT	RT
Wavelength Microns						
.4	.087	.287	.321	.306	.178	.188
.45	.080	.308	.325	.327	.178	.204
.5	.083	.345	.355	.357	.209	[illegible]35
.6	.108	.438	.413	.448	.258	.338
.7	.134	.500	.497	.500	.294	.407
.8	.134	.454	.533	.571	.381	.418
.9	.235	.558	.553	.605	.[illegible]82	.501
1.0	.236	.588	.592	.585	.400	.495
1.2	.269	.573	.585	.572	.407	.509
1.4	.307	.565	.596	.572	.423	.491
1.6	.315	.550	.595	.560	.429	.468
1.8	.340	.524	.581	.535	.438	.439
2.0	.361	.550	.592	.547	.459	.443
2.5	.403	.673	.675	.617	.572	.539
3.0	.341	.760	.779	.786	.694	.588
3.5	.418	.826	.832	.838	.767	.685
4	.511	.861	.860	.872	.804	.745
5	.593	.902	.893	.904	.866	.798
6	.576	.906	.905	.909	.886	.787
7	.344	.888	.880	.893	886	717
8	.361	.867	.912	.921	.903	.687
9	.044	.749	.750	.752	.749	382
10	.046	.939	.774	.785	.795	.375
11	.078	.683	.857	.865	.857	.503
12	.038	.850	.836	.860	.846	453
13	.039	.790	.793	784	786	.252
14	.203	.807	.799	817	.831	269
15	.302	.781	.757	794	803	226
16	.281	789	766	791	.816	282
17	.347	.802	794	808	790	295
18	.420	829	.816	.811	805	294
19	.450	818	821	799	819	259
20	.369	810	815	804	847	[illegible]37
21	.436	776	764	779	806	
22	531				925	

TABLE 17

SPECTRAL REFLECTANCE OF AZ31B MAGNESIUM ANODIZED IN DOW 17

Specimen No.	31	31	31	35	35	35	35	152	152	158
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP	MF	MP
Anodizing Coating	Light	Light	Light	Dark	Dark	Dark	Dark	Light	Light	Dark
Post Treatment	None	None	None	HT-800°F	None	None	None	None	None	None
Spec. Temp.	RT	350°F	RT_f	RT	RT	350°F	RT_f	RT	RT	RT
Wavelength Microns										
.4	.463	.552	.544	.168	.240	.197	.196	.547	.584	.237
.45	.527	.579	.565	.166	.196	.188	.197	.563	.585	.197
.5	.530	581	.580	.226	.254	.246	.271	.580	.599	.271
.6	.551	.588	.588	.243	.253	.264	.251	.595	.618	.249
.7	.543	.590	.593	.245	.264	.238	.259	.596	.587	.253
.8	.576	.570	.577	316	.389	.384	.423	.589	.599	.425
.9	.587	.695	.615	.464	.268	.518	.506	.744	.622	.262
1.0	.575	.629	.609	.518	.244	.532	.542	.673	.631	.285
1.2	.613	.635	.613	.503	.592	.569	.613	.661	.659	.572
1.4	.629	.647	.630	.530	.600	.582	.596	.654	.662	.598
1.6	.628	.669	.636	.526	.595	.610	.591	.659	.662	.591
1.8	.617	.662	.616	.524	.585	.606	.586	.659	.659	.579
2.0	.626	.674	.622	.536	.586	.624	.596	.675	.664	.584
2.5	.701	.739	.718	.547	.570	.635	.627	.749	.739	.578
3.0	.766	.807	.801	.456	.220	.619	.529	.818	.802	.248
3.5	.807	.845	.847	.477	.167	.605	.548	.862	.832	.170
4	.831	.856	.879	.535	.254	.596	.615	.881	.852	.254
5	.875	.888	.898	.418	.331	.599	468	.912	.895	.344
6	.897	.905	.887	.435	.213	404	.412	.919	.902	.242
7	.921	.910	.921	.361	.169	193	.330	.934	912	129
8	.928	.921	.925	.014	038	252	.023	.937	923	.015
9	.928	.924	.929		.038		053	.937	916	035
10	.940	.938	.931	.052	.036		050	.947	.931	055
11	.946	.932	.940	089	078	030	.077	949	941	046
12	.945	.944	.949	.084	.034		.077	.956	941	
13	.940	.954	.949	083			035	956	.948	046
14	.950	.946	.941	.038	.023			955	955	
15	.948	941	932				097	935	.958	044
16	.945	.943	915					950	.929	
17	.938	952	916				039	.927	934	037
18	.942	935	928				122	935	927	
19	.945	.940	921				179	952	935	074
20	.950	929	.898				161	969	941	209
21	975	928	925					981		
22			888					978		

TABLE 18

SPECTRAL REFLECTANCE OF HK31A MAGNESIUM ANODIZED IN DOW 17

Specimen No.	212	213	214	214	214	214
Pretreatment	MP	MP	MP, EP	MP, EP	MP, EP	MP, EP
Anodizing Coating	Light	Dark	Light	Light	Light	Light
Post Treatment	None	None	None	None	None	HT-800°F
Spec. Temp	RT	RT	RT	350°F	RT_f	RT
Wavelength, Microns						
.4	.601	.183	.564	.616	.683	.274
.45	.607	.184	.634	.663	.880	.310
.5	.639	241	.657	.671	.674	.350
.6	.665	.227	673	.677	.713	.382
.7	.673	.219	.668	.703	.688	403
.8	.600	.356	.585	.613	.630	.444
.9	.644	.512	.724	.673	.646	.285
1.0	.697	.532	.646	.665	.659	.446
1.2	.658	.568	.632	.645	.628	.470
1.4	.638	.572	.618	.632	619	.476
1.6	.616	.565	.603	.610	.596	.481
1.8	.575	.539	.557	.608	.566	.475
2.0	.577	.546	565	.613	569	.484
2.5	.679	.563	.677	.680	.676	.616
3.0	.723	.285	.758	.774	.785	.738
3.5	.791	.222	.811	.817	.824	.792
4	.841	.317	.829	834	.846	820
5	.888	.350	.851	.849	860	.848
6	.854	.259	855	.852	859	.858
7	.874	227	865	858	867	.864
8	.898	.035	867	.865	875	873
9	.736	.050	.843	.840	851	.852
10	.787	024	847	850	858	.863
11	.869	.032	869	868	.873	887
12	.899	084	863	864	868	882
13	.912	.053	.856	862	869	867
14	928		839	861	871	884
15	.928	069	854	858	865	893
16	.901		810	821	.819	846
17	886	037	764	779	780	786
18	.868		789	808	.808	827
19	.875	036	787	804	842	840
20	862		800	839	796	847
21	855		791	832	844	895
22	887			827		

TABLE 19

SPECTRAL REFLECTANCE OF A110 AT TITANIUM ANODIZED IN SULFURIC ACID

Specimen No.	38	43
Pretreatment	MP, EP	MP, Pickled
Anodizing Time	Std	Std
Post Treatment	Sealed	Sealed
Spec. Temp.	RT	RT
Wavelength Microns		
.4	.406	.210
.45	.324	.155
.5	.207	.085
.6	.059	.055
.7	.100	.124
.8	.211	.173
.9	.328	.268
1.0	.363	.306
1.2	.469	.460
1.4	.527	.487
1.6	.574	.520
1.8	.605	.554
2.0	.633	.575
2.5	.684	.628
3.0	.736	.673
3.5	.782	.710
4	.805	.726
5	.858	.786
6	.874	.811
7	.890	.839
8	.905	.856
9	915	.868
10	.915	.873
11	.926	895
12	.932	902
13	.931	.907
14	.958	.928
15	946	931
16	.964	.916
17	952	.913
18	.993	918
19	971	918
20	986	920
21	985	910
22	99[illegible]	898

TABLE 20
SPECTRAL REFLECTANCE OF B120 VAC TITANIUM ANODIZED IN SULFURIC ACID

Specimen No.	203	207
Pretreatment	MP, EP	MP Pickled
Anodizing Time	Std	Std
Post Treatment	Sealed	Sealed
Spec. Temp	RT	RT
Wavelength Microns		
.4	.279	.245
.45	.237	.198
.5	.158	.132
.6	.038	.043
.7	076	.063
.8	.206	.185
.9	.347	.131
1.0	.373	.308
1.2	.519	.480
1.4	.594	.528
1.6	.642	.566
1.8	.681	.602
2.0	.708	.626
2.5	.747	.674
3.0	.787	.714
3.5	.802	736
4	.817	.706
5	.844	.777
6	.861	.804
7	.871	.821
8	.880	.839
9	.991	858
10	1 068	857
11	.910	877
12	.916	891
13	928	.895
14	942	889
15	941	913
16	947	938
17	946	944
18	960	932
19	970	935
20	947	931
21	941	932
22	964	

TABLE 21

SPECTRAL REFLECTANCE OF A110AT TITANIUM ANODIZED IN SODIUM HYDROXIDE

Specimen No.	45	45	45	45	45	48
Pretreatment	MP Pickled	MP Pickled	MP Pickled	MP Pickled	MP Pickled	MP, EP
Anodizing Time	Std	Std	Std	Std	Std	Std
Post Treatment	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed
Spec. Temp.	RT	300°F	600°F	900°F	RT_f	RT
Wavelength Microns						
.4	.283	.223	.187	.056	.048	.288
.45	.211	.208	.162	.058	.060	.222
.5	.190	.224	.199	.053	.060	.263
.6	.254	.262	.174	.038	.057	.279
.7	.230	.216	.127	.052	.064	.211
.8	.288	.245	.124	.109	.051	.265
.9	.275	.298	.207	.100	.079	.444
1.0	.351	.367	.227	.125	.075	.480
1.2	.387	.335	.232	.168	.171	.439
1.4	.351	.318	.179	.172	.179	.360
1.6	.315	.283	.148	.171	.194	.323
1.8	.281	.277	.155	.227	.210	.300
2.0	.269	.285	.149	.216	.224	.305
2.5	.308	.344	.245	.251	.206	.391
3.0	.425	.469	.390	.375	.340	.538
3.5	.496	549	.382	.482	.399	.642
4	.616	.595	.551	.438	.423	.687
5	.698	.703	.667	.572	.554	.806
6	.752	743	.726	.643	.627	.837
7	.803	.804	.751	.619	.680	.870
8	.838	.831	777	.720	.727	.886
9	.858	849	811	.719	.765	.900
10	.878	.861	.831	.777	.785	908
11	.897	.859	842	.846	808	.913
12	893	862	849	.838	822	910
13	904	.866	871		.830	.921
14	887	.885	873	783	842	.931
15	865	887	845	813	864	940
16	.902	590	857	789	853	950
17	943	891	905	786	869	956
18	914	895	877	887	866	961
19	892	900	866	839	862	962
20	901	898	881		871	975
21	889	888	876		855	959
22					834	953

TABLE 21 (Continued)

Specimen No.	48	48	48	48	48	178
Pretreatment	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP
Anodizing Time	Std	Std	Std	Std	Std	Std/3
Post Treatment	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed
Spec. Temp.	500°F	1000°F	RT_f(1000 F)	1300°F	RT_f(1300 F)	RT
Wavelength Mic. s						
.4	.206	.077	.069	152	182	.262
.45	.219	083	110	.169	171	209
.5	.279	092	.121	.179	178	.250
.6	.210	.122	.142	.220	.219	297
.7	172	.162	.183	250	.260	.222
.8	.265	.211	.293	.260	.375	.271
.9	.239	264	.324	.356	.394	403
1.0	.246	.305	.343	.364	.417	449
1.2	294	.351	.433	.401	500	.424
1.4	247	381	.481	440	.535	367
1 6	.208	419	.502	446	.556	.322
1.8	.231	.449	.542	525	.585	.289
2.0	.266	.508	568	.464	.609	.290
2.5	.400	527	620	452	.657	369
3.0	.554	.822	.662	.588	692	505
3.5	.639	.692	.707	.618	.721	595
4	675	.644	.724	.641	730	.647
5	761	733	.776	663	.771	751
6	.806	737	807	704	806	787
7	.831	.733	834	710	826	823
8	.852	783	853	736	850	847
9	870	818	874	746	862	856
10	881	.808	885	783	873	860
11	913	882	895	781	891	863
12	910	858	899	808	891	848
13	921	853	903	813	911	853
14	.931	880	922	838	931	854
15	940	901	937	837	932	867
16	950	892	937	842	932	853
17	956	899	951	873	953	854
18	961	927	962	880	952	876
19	962	955	964	818	966	876
20	975	921	955	835	982	894
21	959	896	957	927	[illegible]	915
22	953	834	911	838	1.016	847

TABLE 22

SPECTRAL REFLECTANCE OF A110AT TITANIUM ANODIZED BY A PROPRIETARY PROCESS

Specimen No.	37	41	47	47	47	47	47
Pretreatment	MP, EP	MP Pickled	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP
Anodizing Time	Thin Coat	Std	Std	Std	Std	Std	Std
Post Treatment	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed
Spec. Temp.	RT	RT	RT	500°F	1000°F	1300°F	RT_f
Wavelength Microns							
.4	.145	.144	.158	.156	.067	.124	.117
.45	.156	.157	.157	.162	.084	.108	.118
.5	.160	.164	.158	.161	.088	.109	.123
.6	.165	.174	.165	.167	.078	.116	.135
.7	.171	.18[illegible]	.171	.175	.081	.128	.168
.8	.208	.248	.211	.206	.112	.269	.224
.9	.206	.224	.235	.212	.095	.240	.262
1.0	.207	.243	.225	.233	.069	290	.301
1.2	233	.288	.251	.174	097	.316	.326
1.4	.261	.306	.290	.284	.090	.338	.334
1.6	.282	.328	.315	.309	.114	.346	.350
1.8	.302	.356	.342	.335	.120	.[illegible]35	.362
2.0	.323	.374	.354	.358	.163	.321	.374
2.5	.387	.464	.417	.407	.185	.267	.390
3.0	.490	.583	.539	529	.239	.262	.407
3.5	.544	.636	.630	.625	.199	279	.423
4	.557	649	658	.650	.243	.260	.441
5	.492	.618	.638	.595	.188	225	.474
6	.559	671	.651	614	.243	.589	.502
7	.668	787	757	720	381	.592	528
8	.679	.792	.738	.744	.511	.661	536
9	.526	654	587	581	.544	.669	571
10	.347	490	404	.421	.448	657	595
11	358	492	[illegible]	328	404	706	608
12	486	640	554	542		.720	.627
13	595	.751	659	633	576		624
14	.658	810	731	742		.837	709
15	.696	.858	799	759	772		709
16	.705	866	823	808			750
17	715	876	842	806	789		777
18	.745	909	874	847			772
19	784	936	883	851	858		785
20	811	932	898	[illegible]			798
21	799	927	880	909	869		837
22	841	915	877	914			

TABLE 23

SPECTRAL REFLECTANCE OF B120 VAC TITANIUM ANODIZED BY A PROPRIETARY PROCESS

Specimen No.	197	199	201	201	201	201	201
Pretreatment	MP, EP	MP, Pickled	MP, EP	MP, EP	MP, EP	MP, EP	MP, EP
Anodizing Time	Thin Coat	Std	Std	Std	Std	Std	Std
Post Treatment	Sealed	Sealed	Sealed	Sealed	Sealed	HT 1500°F	None
Spec. Temp.	RT	RT	RT	500°F	1000°F	RT	RT
Wavelength Microns							
.4	.133	.113	.123	.106	.105	.127	.084
.45	.141	.144	.150	.136	.105	.121	.090
.5	.152	.149	.146	.147	.097	.120	.090
.6	.168	.165	.161	.160	.096	.121	.088
.7	.174	.167	.172	.171	.102	.117	.089
.8	.216	.210	.219	.123	.108	.144	.096
.9	.219	.191	.223	.173	.114	.111	.077
1.0	.242	.229	.327	.176	.113	.134	.087
1.2	.273	.287	.278	.262	.093	.135	.091
1.4	.294	.325	.231	.210	.060	.141	.092
1.6	.316	.344	.326	.296	.087	.139	.096
1.8	.344	.380	.355	.322	.070	.144	.104
2.0	.367	.400	.363	.342	.028	.147	.114
2.5	.409	.452	.418	.379	.053	.156	.127
3.0	.474	.496	.484	.464	.062	.170	.113
3.5	.476	.599	.495	.453	.209	.186	.145
4	.477	.661	.498	.449	.100	.192	.189
5	.631	716	571	.622	.274	.184	.308
6	.699	687	.724	.672	.199	.270	.278
7	.668	.740	.705	.623	.183	.383	.228
8	.432	.695	.485	.416	.252	.286	.354
9	.259	.471	.296	.284	.374	.062	269
10	.189	.275	.228	.136	.262	.128	.185
11	.172	.238	.196	.269	.418	.161	.159
12	.087	.311	.110	.136		.127	062
13	.067	473	.119	.078	420	.299	167
14	.142	629	174	.273		.398	312
15	.286	.698	.306	.355	.467	408	407
16	.317	721	.345	420		.428	424
17	.307	.748	.390	.393	494	533	459
18	370	.759	498	480		580	.505
19	.448	840	563	490	572	658	601
20	.546	852	608	569		554	621
21	.540	845	619	562	716	466	665
22		865	596	729			

TABLE 24

SPECTRAL REFLECTANCE OF BERYLLIUM, 1% COPPER, ANODIZED IN SULFURIC ACID

Specimen No.	162
Pretreatment	MP
Anodizing Time	Std
Post Treatment	Sealed
Spec. Temp.	RT
Wavelength Microns	
.4	.250
45	.292
.5	.282
.6	.292
.7	.284
.8	302
.9	.357
1.0	.350
1.2	.422
1.4	.507
1 6	.563
1.8	.614
2.0	658
2.5	.732
3.0	781
3.5	809
4	.825
5	843
6	.847
7	.848
8	.858
9	845
10	817
11	.797
12	.800
13	802
14	.806
15	.817
16	812
17	823
18	835
19	808
20	809
21	800
22	786

TABLE 25

SPECTRAL REFLECTANCE OF BERYLLIUM, 1% COPPER, ANODIZED IN SODIUM HYDROXIDE

Specimen No.	164	166	166	166	166	166
Pretreatment	MP, EP	MP	MP	MP	MP	MP
Anodizing Time	Std	Std	Std	Std	Std	Std
Post Treatment	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed
Spec. Temp.	RT	RT	400°F	800°F	1200°F	RT_f
Wavelength Microns						
.4	.081	.051	.054	.050	.093	.074
.45	.071	.051	.047	.030	.077	.084
.5	.068	.050	.047	041	.080	.083
.6	.066	.044	040	.037	.078	100
.7	.062	.049	047	.050	.105	.121
.8	.059	.080	.051	.117	.128	.197
.9	.095	.057	.067	.084	169	.123
1.0	062	.083	098	.116	.186	.144
1.2	.085	.104	.100	.125	.198	.230
1.4	.095	.094	.134	215	.241	.304
1.6	.101	.108	.201	.296	378	.406
1.8	.102	.183	.291	.396	.501	.542
2.0	.099	.249	.345	.458	.543	.609
2.5	.100	.388	.416	.527	.576	.678
3.0	.123	372	.424	.573	.628	.703
3.5	.180	.394	.478	609	.658	.707
4	.215	.410	.495	639	.668	.731
5	.415	.528	.661	.770	.757	.822
6	.562	662	750	.815	.817	.857
7	.636	.782	.805	942	.878	875
8	682	.850	.847	866	.849	.901
9	.680	842	829	831	.804	.870
10	660	.818	803	814	.768	.851
11	.675	.826	803	815	803	.849
12	.672	828	820	814	.858	867
13	681	807	807	.832	871	.871
14	691	.734	765	826	835	783
15	670	686	.749	799	675	762
16	.713	825	1 108	837	817	.891
17	752	905	889	954	867	931
18	759	938	.935	906	.898	948
19	773	945	945	934	901	960
20	783	975	931	974	946	1 029
21	[illegible]	952	[illegible]	962	857	953
22	[illegible]				886	953

TABLE 26

SPECTRAL REFLECTANCE OF QMV BERYLLIUM ANODIZED IN SODIUM HYDROXIDE

Specimen No.	173	173	173	173	173	177	177
Pretreatment	MP	MP	MP	MP	MP	MP, EP	MP, EP
Anodizing Time	Std	Std	Std	Std	Std	Std	Std
Post Treatment	Sealed	Sealed	Sealed	Sealed	Sealed	Sealed	Std HT-1500°F
Spec. Temp.	RT	400°F	800°F	1200°F	RT_f	RT	RT
Wavelength Microns							
.4	.208	.259	.217	.144	.201	.075	.271
.45	.217	.229	.237	.160	.192	.057	.285
.5	.220	.235	.240	.154	.119	.054	.294
.6	.219	229	.230	.116	.068	.052	.295
.7	.223	.240	.231	.124	167	.050	.300
.8	.271	.265	.225	.116	.241	.058	.365
.9	.226	.261	.160	.101	.284	.037	.340
1.0	.262	.258	.273	.102	.287	.068	.342
1.2	.360	.296	.312	.100	.277	.092	.415
1.4	.353	.362	.355	.114	.252	059	.488
1.6	.402	.405	.389	.159	.254	.071	.547
1.8	.444	.428	.437	249	.282	.139	.603
2.0	465	.462	.461	.260	.314	.203	.640
2.5	.517	.525	.539	.385	.427	.312	.720
3.0	.566	.577	.603	.461	.584	.309	.762
3.5	.607	.630	.634	.593	671	.298	.796
4	.637	.645	.654	.633	.729	.286	.827
5	.572	.6[illegible]	.729	.691	800	.351	.846
6	.708	.741	.787	.739	.829	.514	.827
7	.772	.787	.812	.789	.855	.667	.784
8	.831	.833	.839	.805	.882	.772	.850
9	.870	.854	857	.832	874	771	.789
10	.890	.864	862	.831	.870	.733	.693
11	.884	.885	869	.818	.903	742	.696
12	.899	894	.886	.909	909	.725	.647
13	904	.904	.889	882	.895	.729	.654
14	.903	883	.90[illegible]	.960	.903	.708	638
15	.881	881	.898	.831	.810	606	.242
16	.887	923	.903	855	.859	735	.568
17	941	.551	.945	881	905	796	.793
18	.959	950	.953	906	.953	865	.859
19	968	.971	.945	897	967	865	890
20	905	975	.947	968	969	899	704
21	959	.868	[illegible]	1.034	956	919	92[illegible]
22			972			.869	911

TABLE 27

SPECTRAL REFLECTANCE OF BERYLLIUM, 1% COPPER, ANODIZED IN NITRIC ACID

Specimen No.	167
Pretreatment	MP
Anodizing Time	Std
Post Treatment	Sealed
Spec. Temp.	RT
Wavelength Microns	
.4	.018
.45	.009
.5	.013
.6	.013
.7	.015
.8	.016
.9	.011
1.0	.035
1.2	.032
1.4	.043
1.6	.055
1.8	.068
2.0	.088
2.5	.151
3.0	.161
3.5	.242
4	.305
5	.441
6	.415
7	.426
8	.379
9	.137
10	.055
11	.095
12	.142
13	.180
14	.242
15	.099
16	.234
17	.254
18	.518
19	459
20	.[illegible]50
21	506
22	535

TABLE 28

SPECTRAL REFLECTANCE OF QMV BERYLLIUM ANODIZED IN NITRIC ACID

Specimen No.	174	176
Pretreatment	[illegible]	MP
Anodizing Time	Std	Std/3
Post Treatment	Sealed	Sealed
Spec. Temp.	RT	RT
Wavelength Microns		
.4	.016	.013
.45	.017	.016
.5	.011	.012
.6	.015	.008
.7	.015	.022
.8	.029	.028
.9	.015	.026
1.0	.029	.027
1.2	.036	.053
1.4	.030	.080
1.6	.039	.116
1.8	.052	.142
2.0	.065	.169
2.5	.107	.243
3.0	.104	.231
3.5	.175	.355
4	.225	.423
5	.342	534
6	.347	554
7	.317	.452
8	.345	.496
9	.105	.113
10	.121	.033
11	069	044
12	065	053
13	.175	070
14	059	.120
15	149	.171
16	127	.269
17	136	314
18	274	341
19	303	436
20	334	390
21	309	444
22		534

TABLE 29

SPECTRAL REFLECTANCE OF BERYLLIUM, 1% COPPER, ANODIZED IN CHROMIC ACID

Specimen No.	168	170
Pretreatment	MP	MP
Anodizing Time	Std	Std/3
Post Treatment	Sealed	Sealed
Spec. Temp.	RT	RT
Wavelength Microns		
.4	.169	.341
.45	.164	.354
.5	.166	.367
.6	.162	.367
.7	.162	.377
.8	.133	.462
.9	.160	.438
1.0	.161	.451
1.2	.192	.528
1.4	.218	.580
1.6	.228	.650
1.8	.249	.704
2.0	.269	.679
2.5	.293	.764
3.0	.307	.787
3.5	.335	.789
4	.349	.791
5	.350	.768
6	.361	.756
7	.365	.778
8	.333	.810
9	.317	.839
10	.459	.855
11	.531	.866
12	.613	.870
13	677	.874
14	.701	.866
15	.678	856
16	538	864
17	556	896
18	462	.909
19	653	877
20	334	.886
21	504	889
22		911

TABLE 30

SPECTRAL REFLECTANCE OF QMV BERYLLIUM ANODIZED IN CHROMIC ACID

Specimen No.	172
Pretreatment	MP
Anodizing Time	Std
Post Treatment	Sealed
Spec. Temp.	RT
Wavelength Microns	
.4	.172
.45	.184
.5	.187
.6	.179
.7	.173
.8	.168
.9	.210
1.0	.165
1.2	.202
1.4	.232
1.6	.249
1.8	.264
2.0	.280
2.5	.308
3.0	.303
3.5	.318
4	.355
5	.354
6	.335
7	.296
8	317
9	.461
10	.560
11	.618
12	666
13	712
14	.729
15	673
16	494
17	416
18	459
19	385
20	494
21	594
22	

TABLE 31

SPECTRAL REFLECTANCE OF UNANODIZED METALS

Specimen No.	18	156	171	46	209	202
Material	Aluminum	Magnesium	Beryllium	Titanium	Titanium	Titanium
Alloy	1075	AZ 31B	1% Cu.	A110AT	A110AT	B120 VAC
Pretreatment	MP, EP	MP	MP	MP, EP	MP	MP, EP
Spec.Temp.	RT	RT	RT	RT	RT	RT
Wavelength Microns						
.4	.708	.586	.356	.463	.365	.522
.45	.740	.592	.372	.534	.417	.512
.5	.737	.593	.377	.579	.443	.517
.6	.731	.623	.371	.569	.458	.524
.7	.710	.638	.374	.573	.475	.515
.8	.711	.647	.396	.589	.479	.543
.9	.740	.709	.386	.625	.528	.552
1.0	.783	.696	.425	.629	.551	.591
1.2	.852	.736	.521	.679	.571	.616
1.4	.865	.751	.613	.670	.588	.662
1.6	.853	.762	.646	.689	.608	.686
1.8	.870	.761	.673	.716	.626	.703
2.0	.861	.767	.703	.732	.640	.726
2.5	.883	.814	.728	.760	.678	.750
3.0	.865	.873	.758	.796	.716	.777
3.5	.879	.912	.781	.831	.738	.815
4.0	.902	.922	.777	.840	.754	.811
5	.917	.943	.764	.883	.798	.831
6	.982	.953	.779	.905	.818	.863
7	.912	.956	.816	.918	.839	.873
8	.803	.958	.818	.934	.855	.886
9	.703	.960	.834	.949	.870	.890
10	.831	.956	.843	.950	.879	.903
11	.807	.975	.817	.964	.902	.907
12	.769	.975	.853	.968	.910	.916
13	.770	.979	.855	.973	.908	.927
14	.790	.984	.845	.990	.904	.946
15	.808	.980	.854	.989	.933	.969
16	.839	.979	.847	1.002	.906	.968
17	.844	.978	.867	1 003	939	959
18	.863	.987	.859	1.011	.934	.974
19	.874	.993	.858	1 014	934	.977
20	.876	.981	.856	1.019	.954	976
21			884	1 021		980
22			861	1 034		981

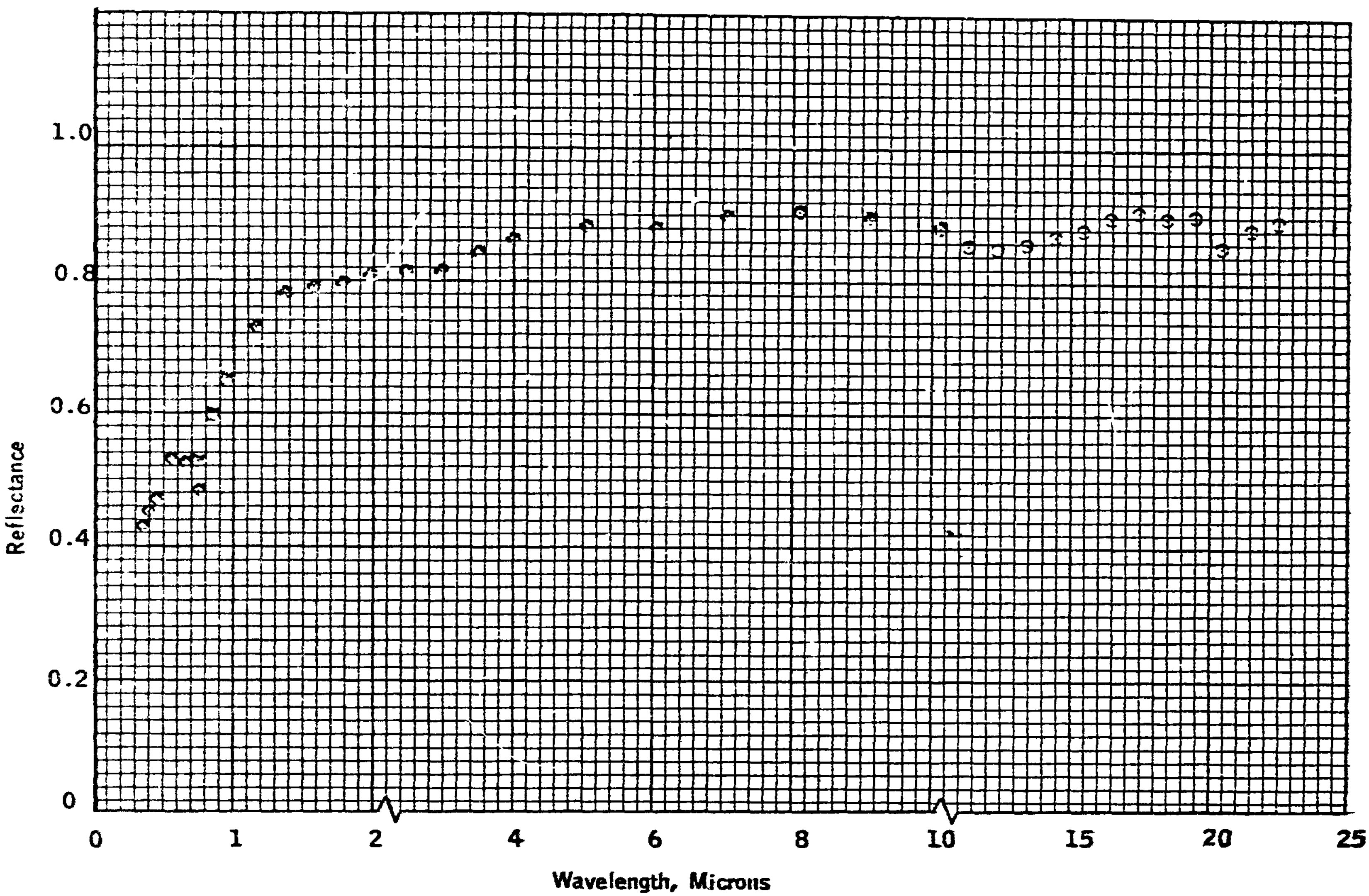


Fig. 23 Normal Spectral Reflectance of Specimen No 50 Temperature RT

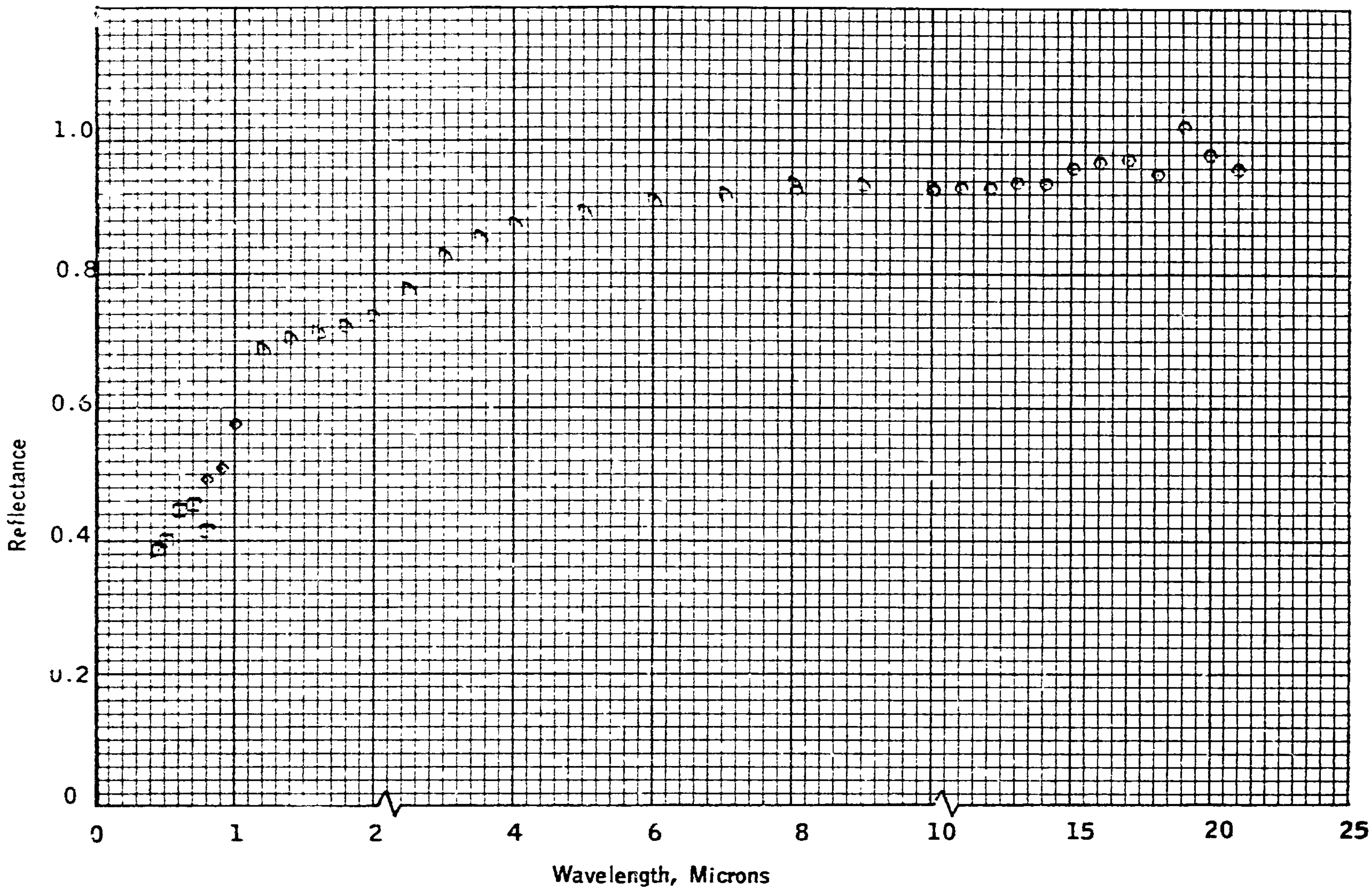


Fig. 24 Normal Spectral Reflectance of Specimen No 50 Temperature 600 F

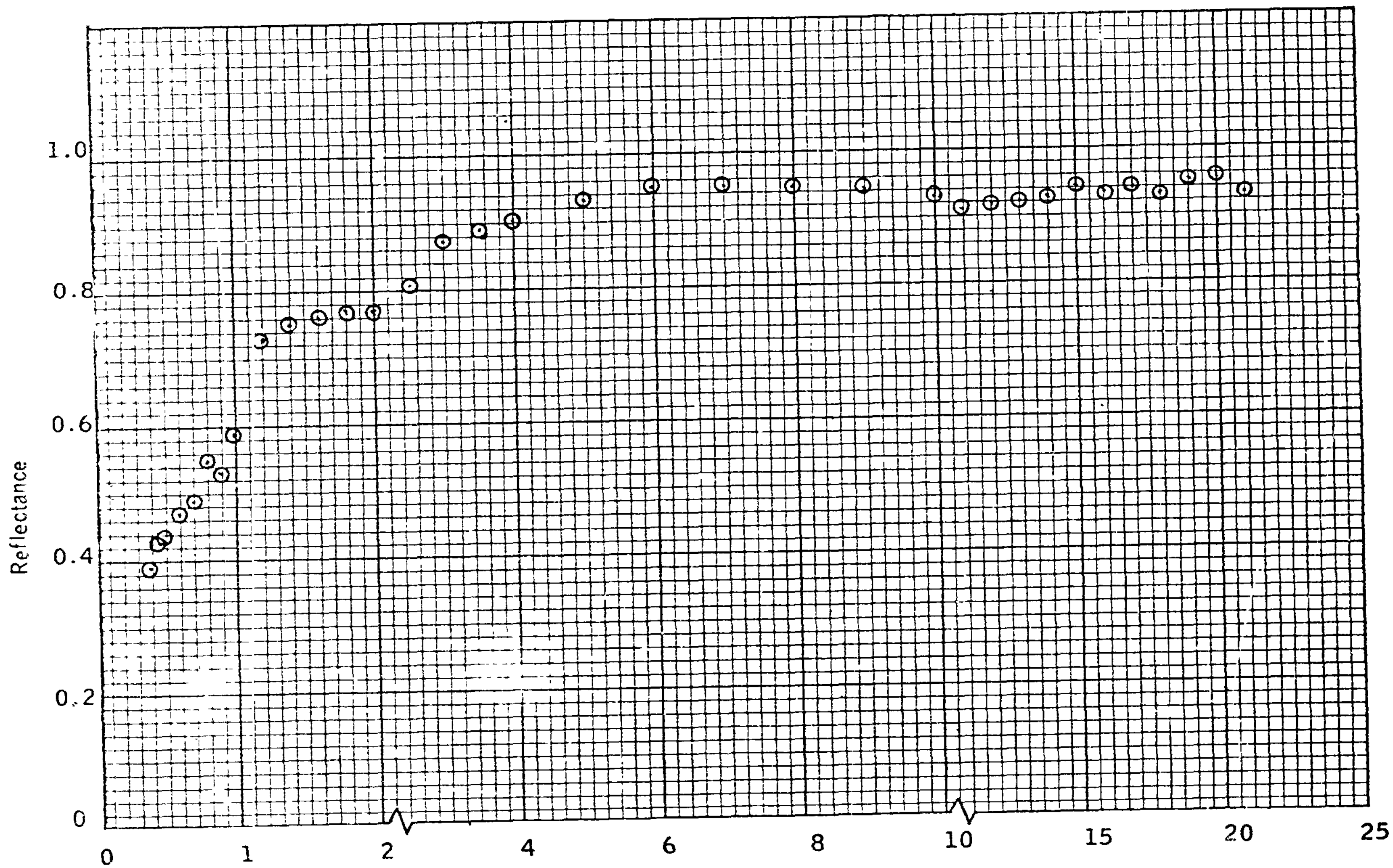


Fig. 25 Normal Spectral Reflectance of Specimen No 50 Temperature RT_f

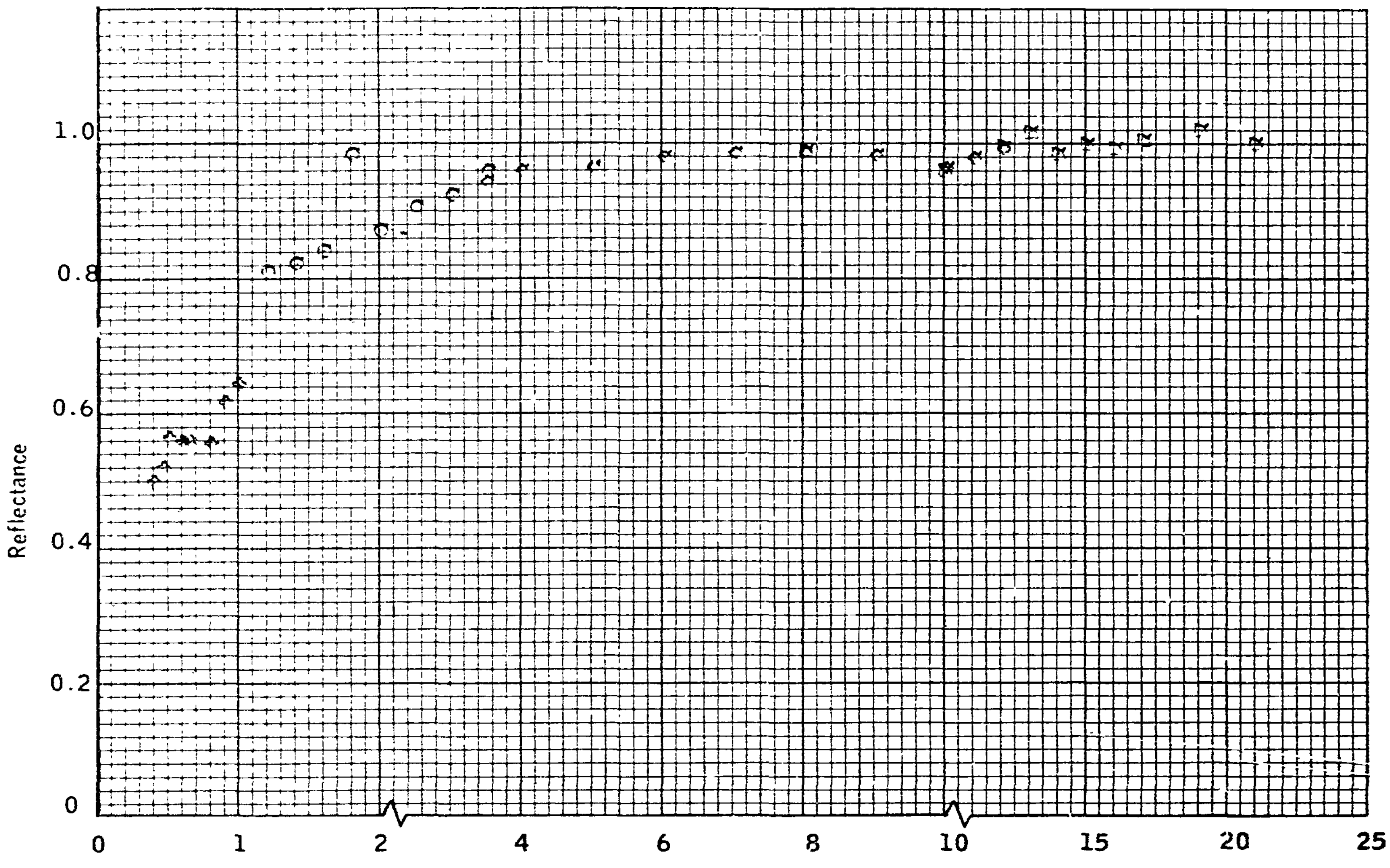


Fig. 26 Normal Spectral Reflectance of Specimen No 51 Temperature RT

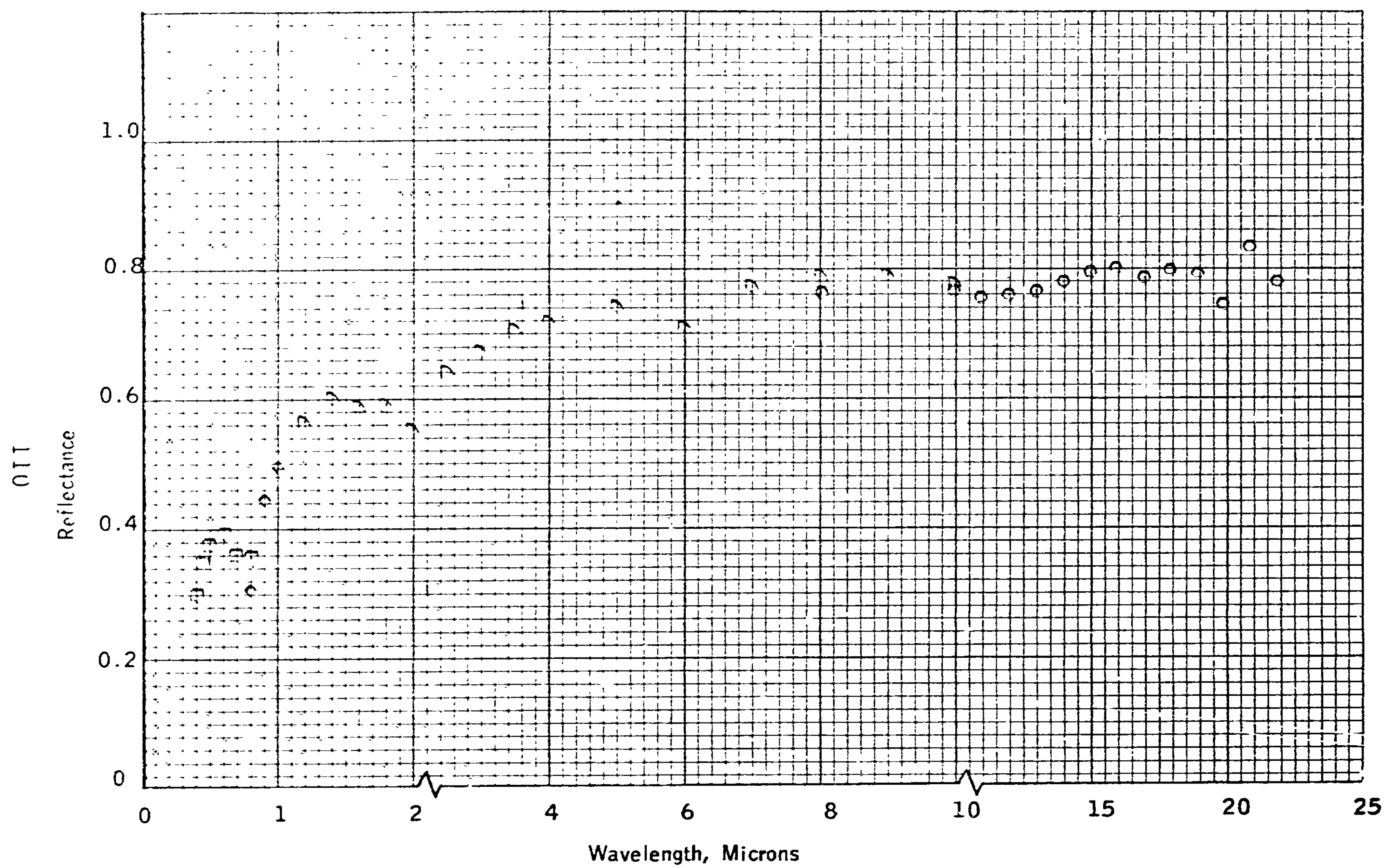


Fig. 27 Normal Spectral Reflectance of Specimen No 75 Temperature RT

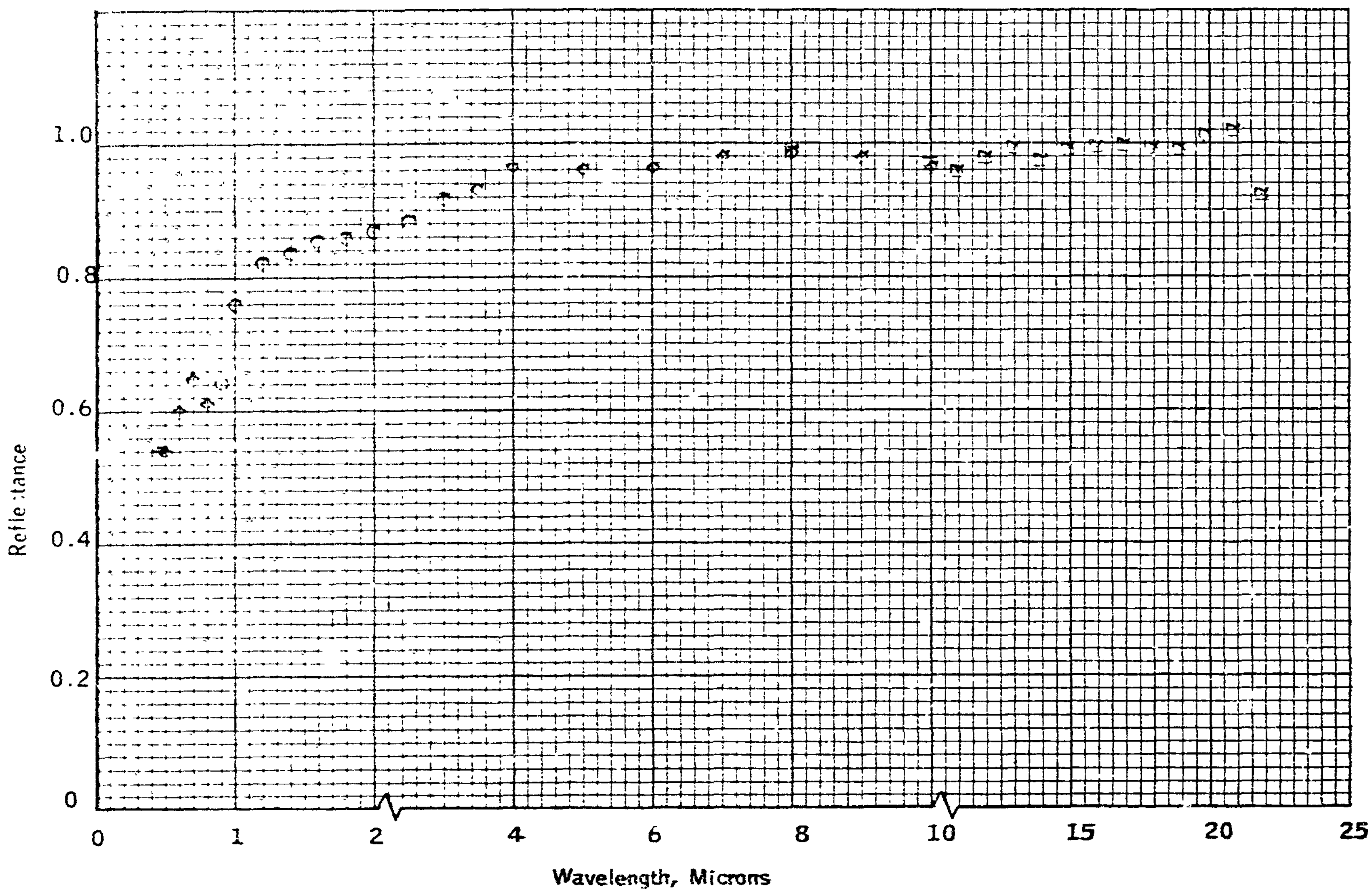


Fig. 28 Normal Spectral Reflectance of Specimen No 110 Temperature RT

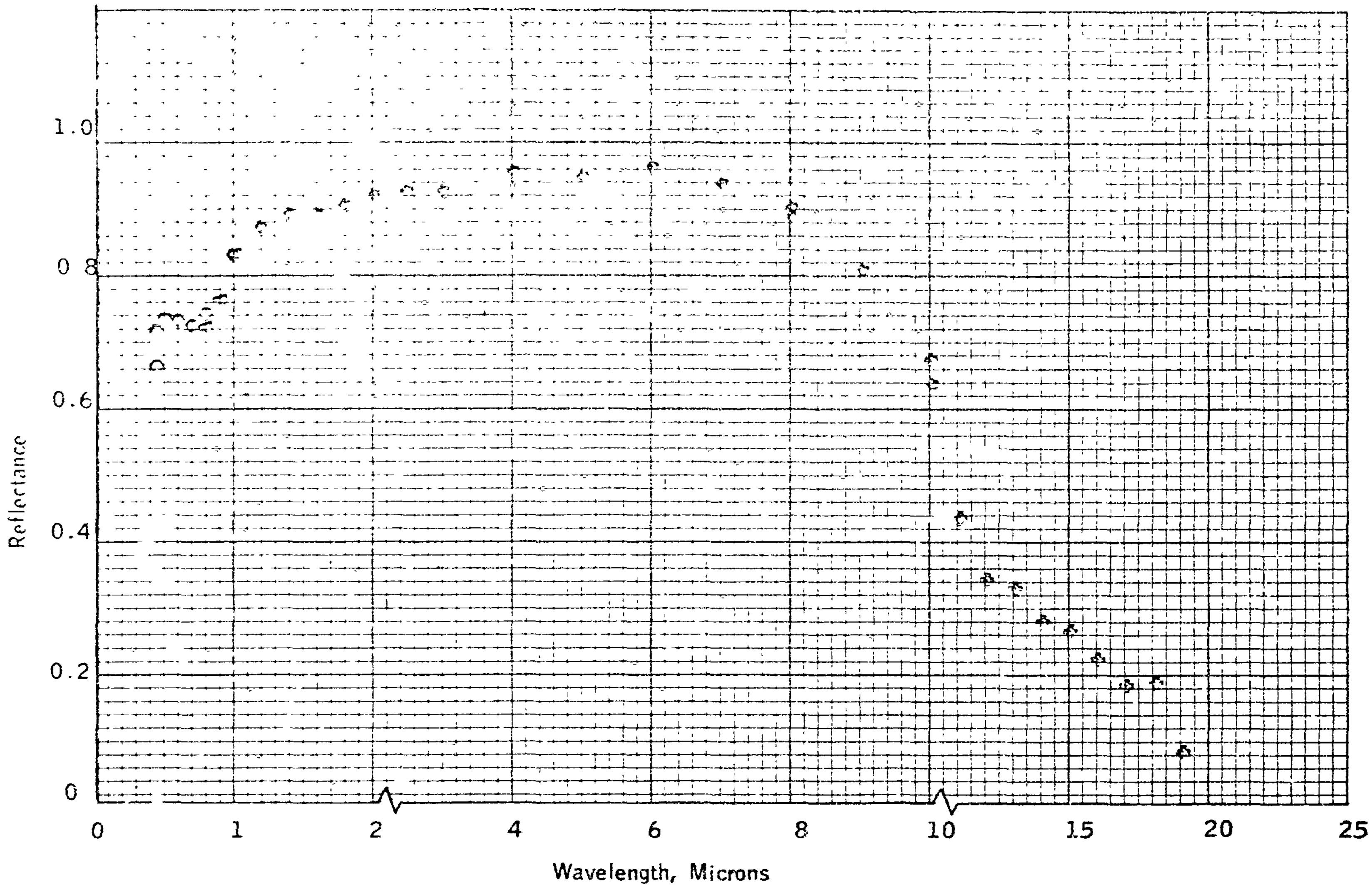


Fig. 29 Normal Spectral Reflectance of Specimen No 55 Temperature RT

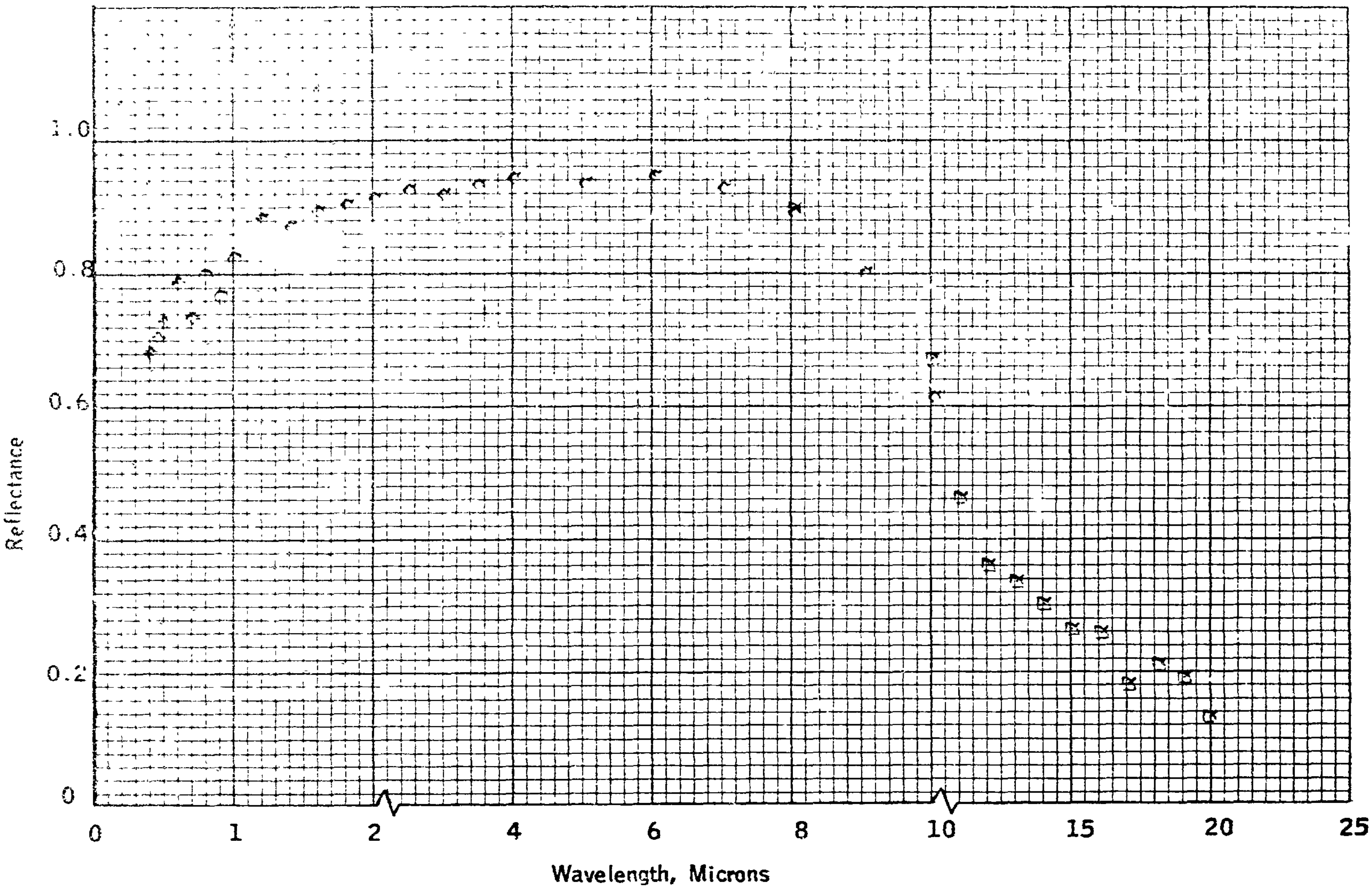


Fig. 30 Normal Spectral Reflectance of Specimen No 55 Temperature 300 F

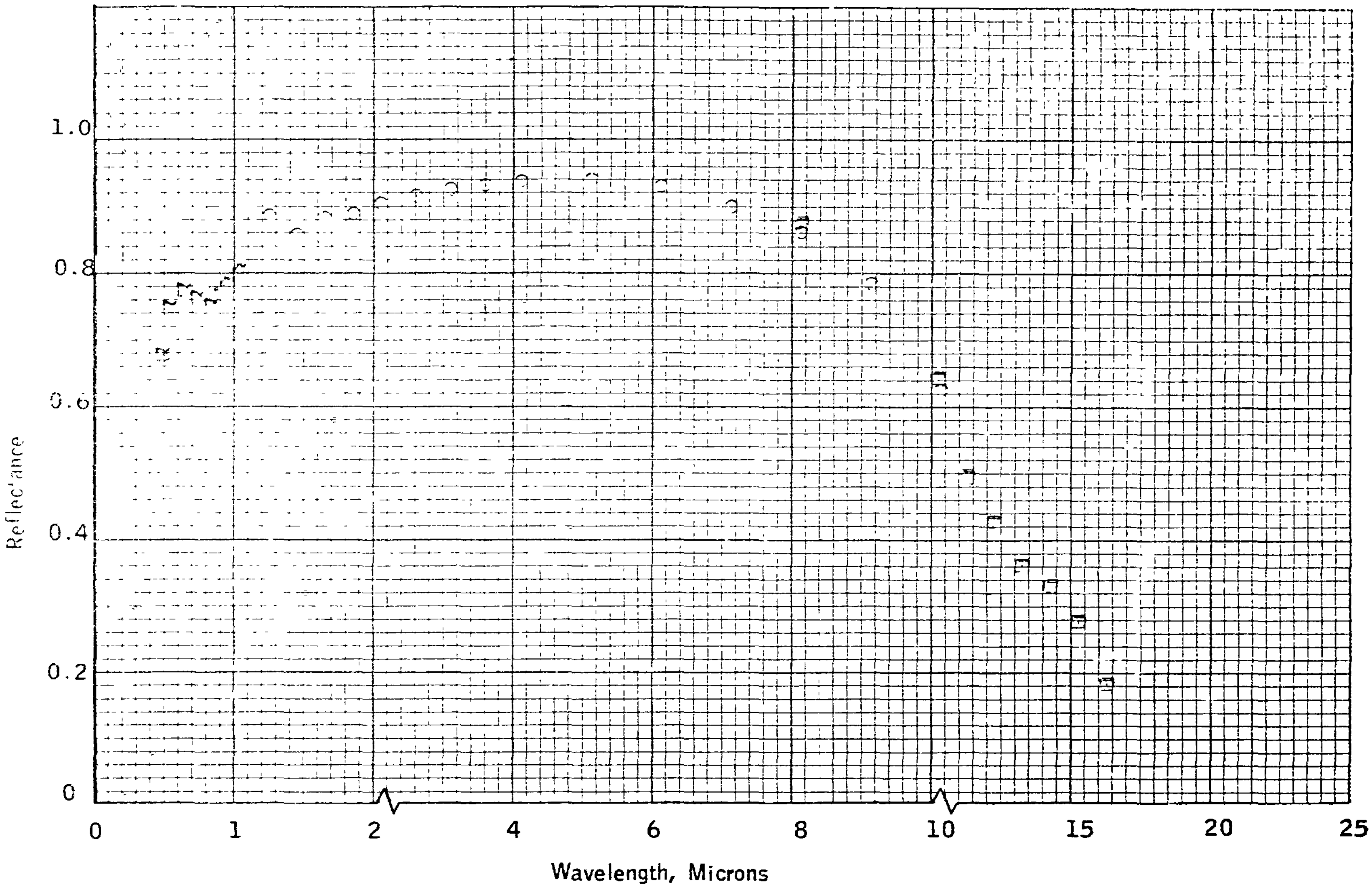


Fig. 31 Normal Spectral Reflectance of Specimen No 55 Temperature 600 F

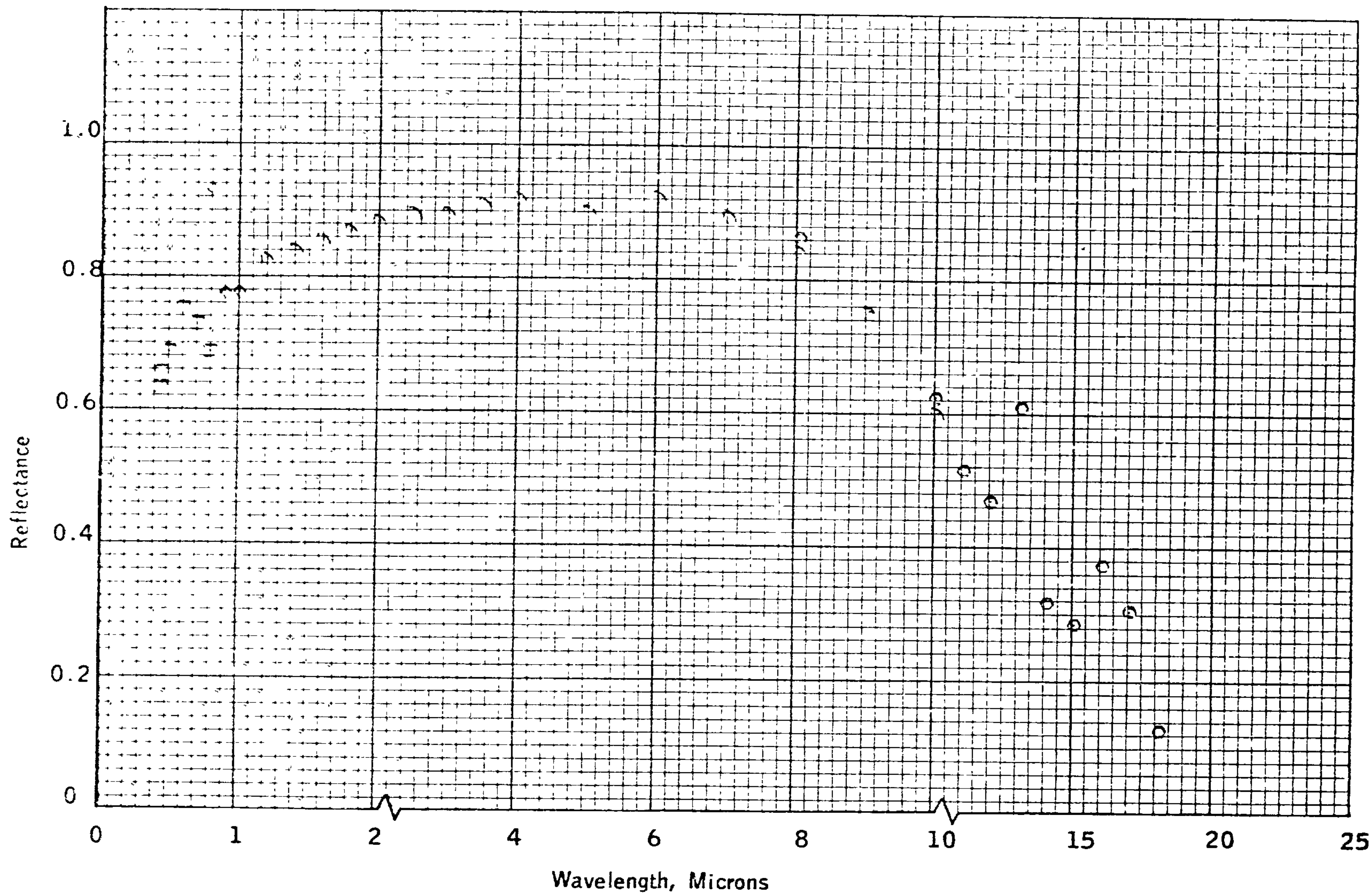


Fig. 32 Normal Spectral Reflectance of Specimen No 55 Temperature 825 F

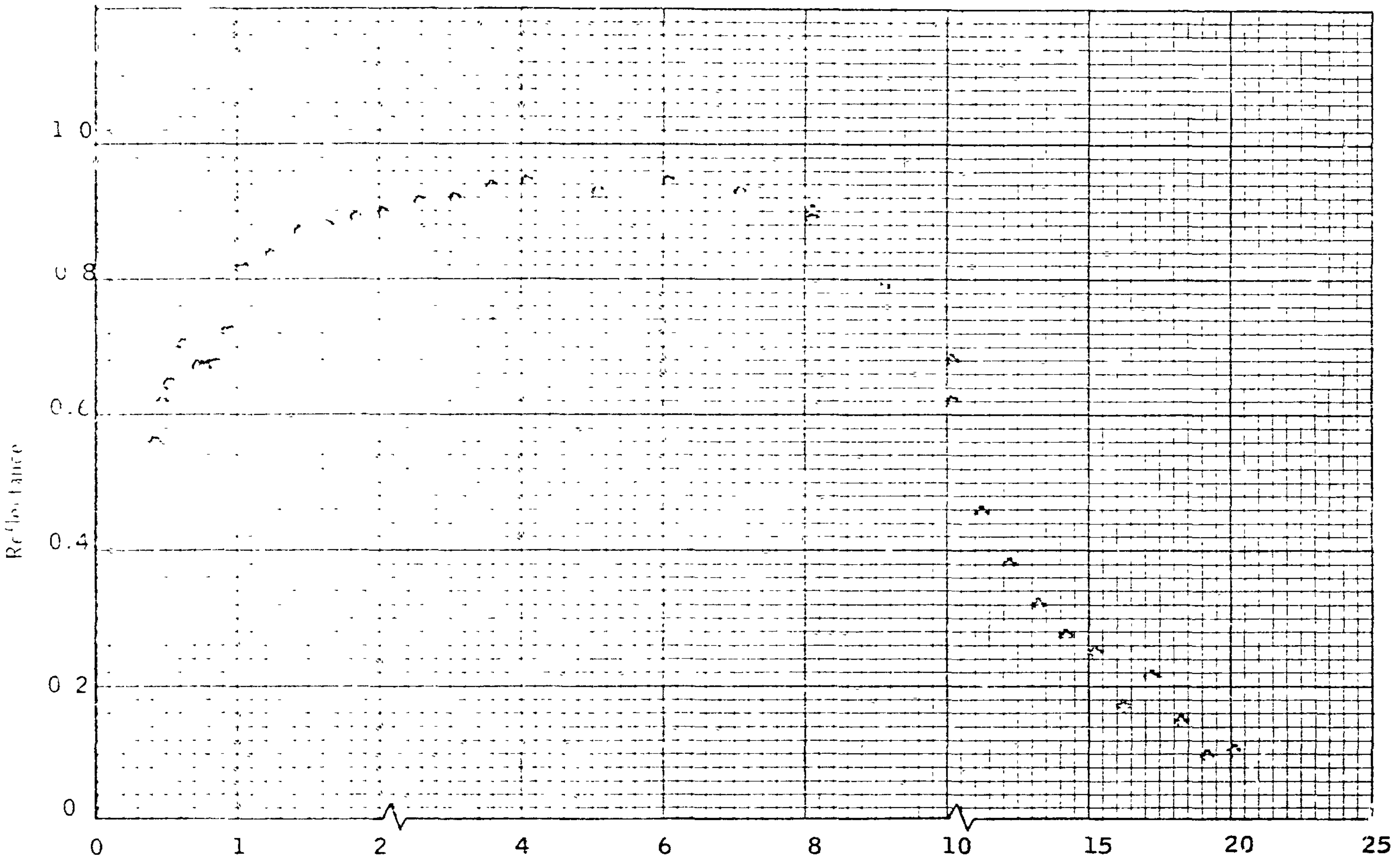


Fig. 33 Normal Spectral Reflectance of Specimen No 55 Temperature RT_f

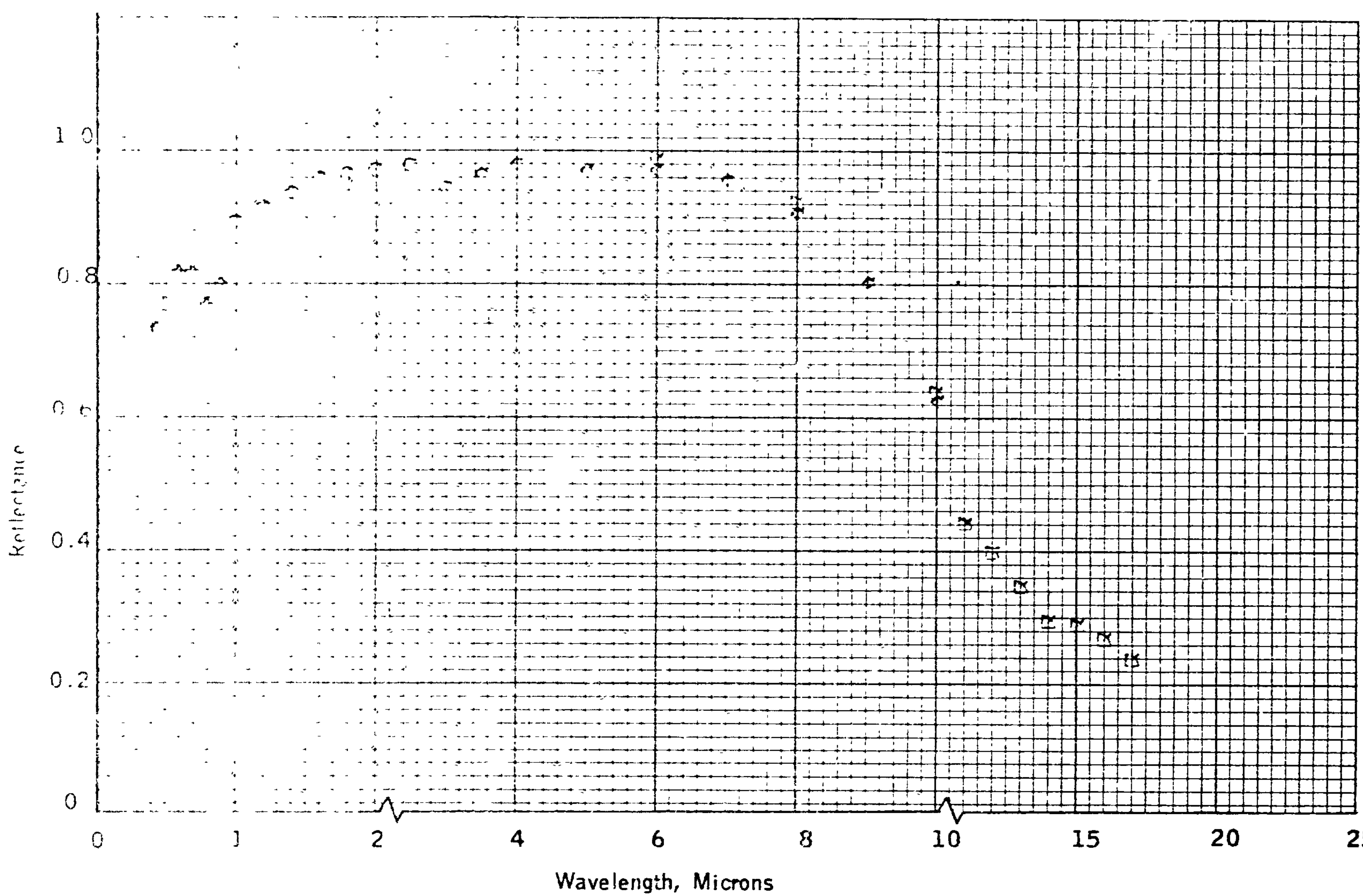


Fig. 34 Normal Spectral Reflectance of Specimen No 56 Temperature RT, HT-800F

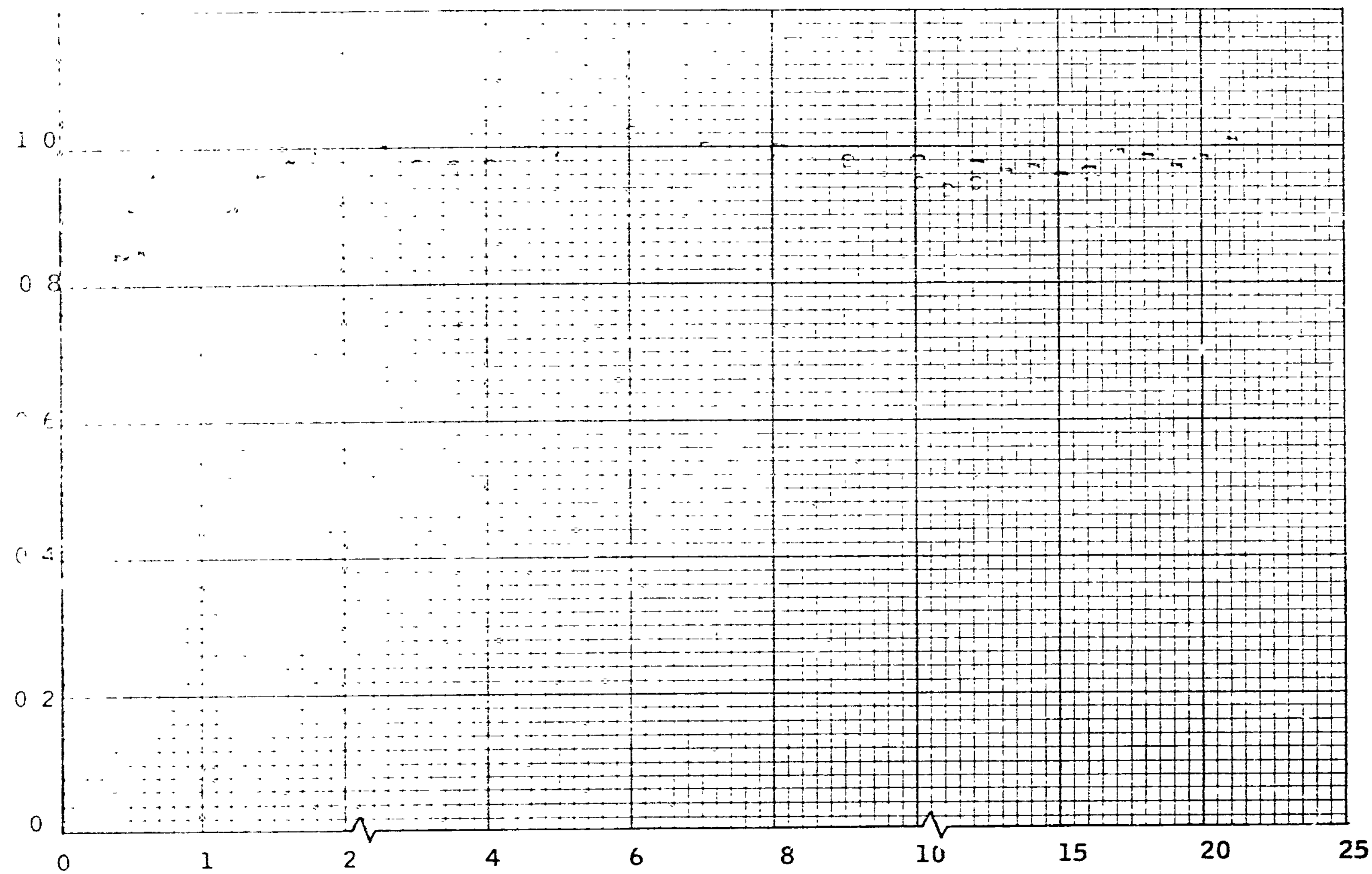


Fig. 35 Normal Spectral Reflectance of Specimen No 57 Temperature RT

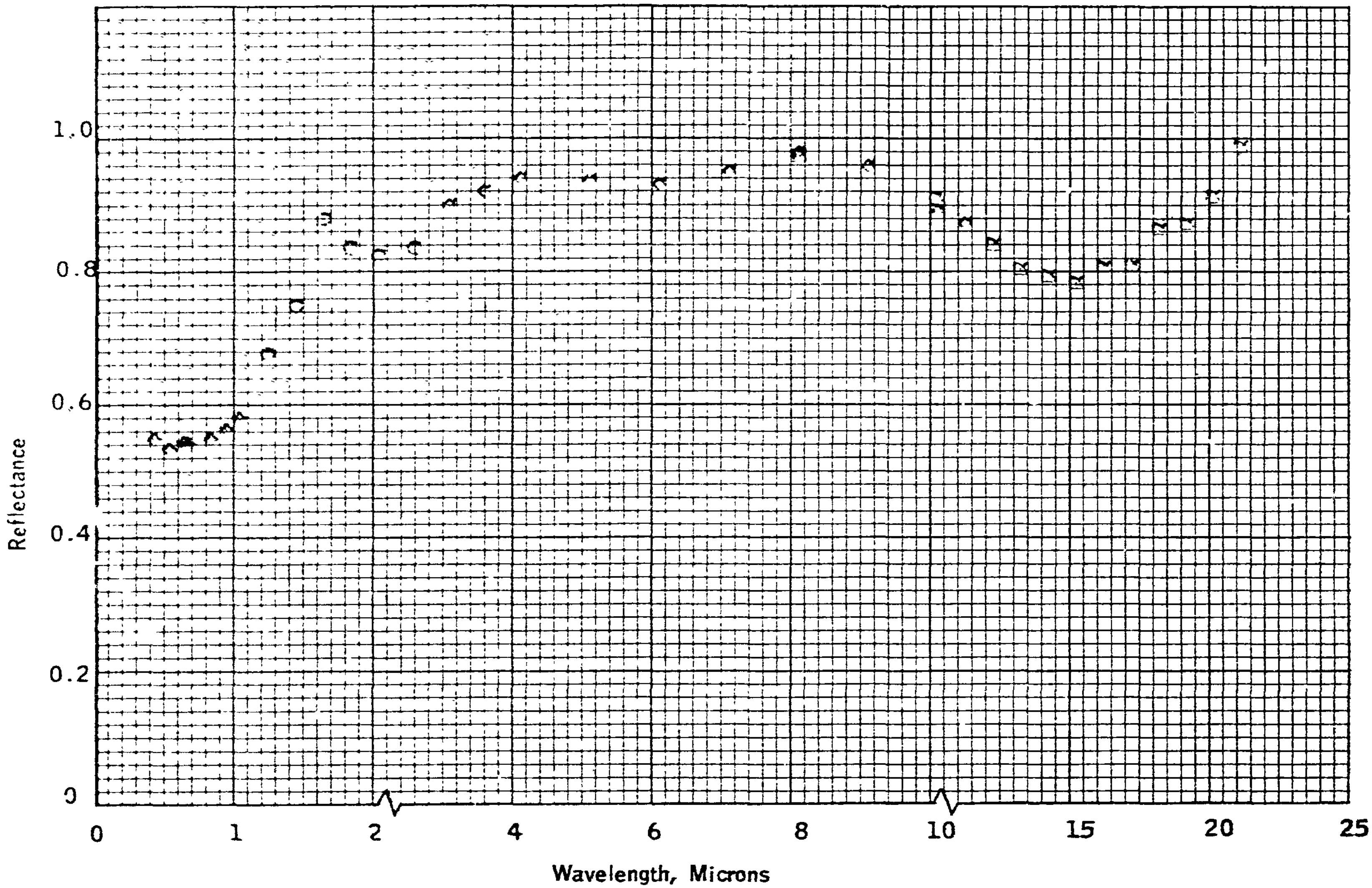


Fig. 36 Normal Spectral Reflectance of Specimen No 83 Temperature RT

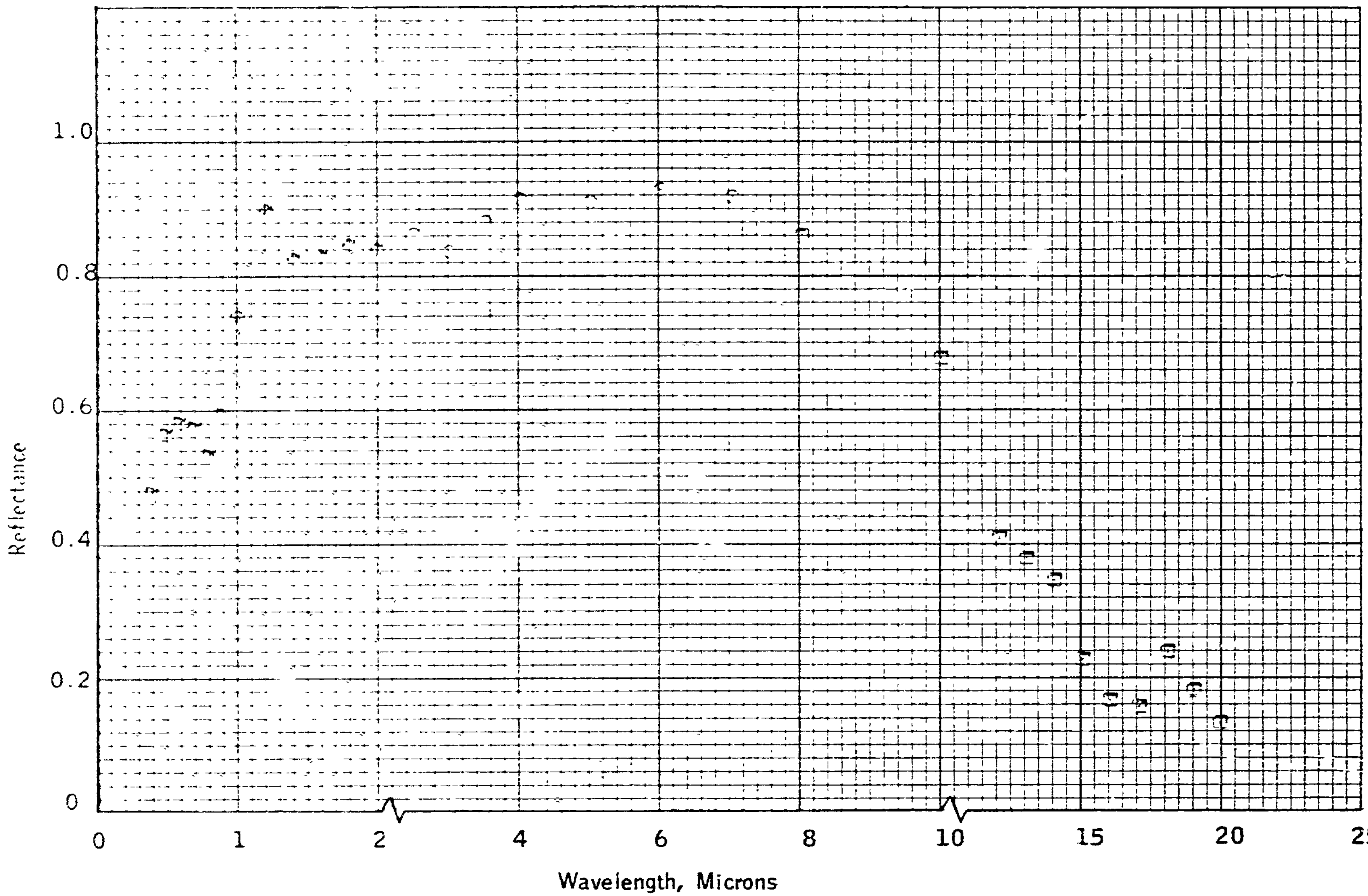


Fig. 37 Normal Spectral Reflectance of Specimen No 84 Temperature RT

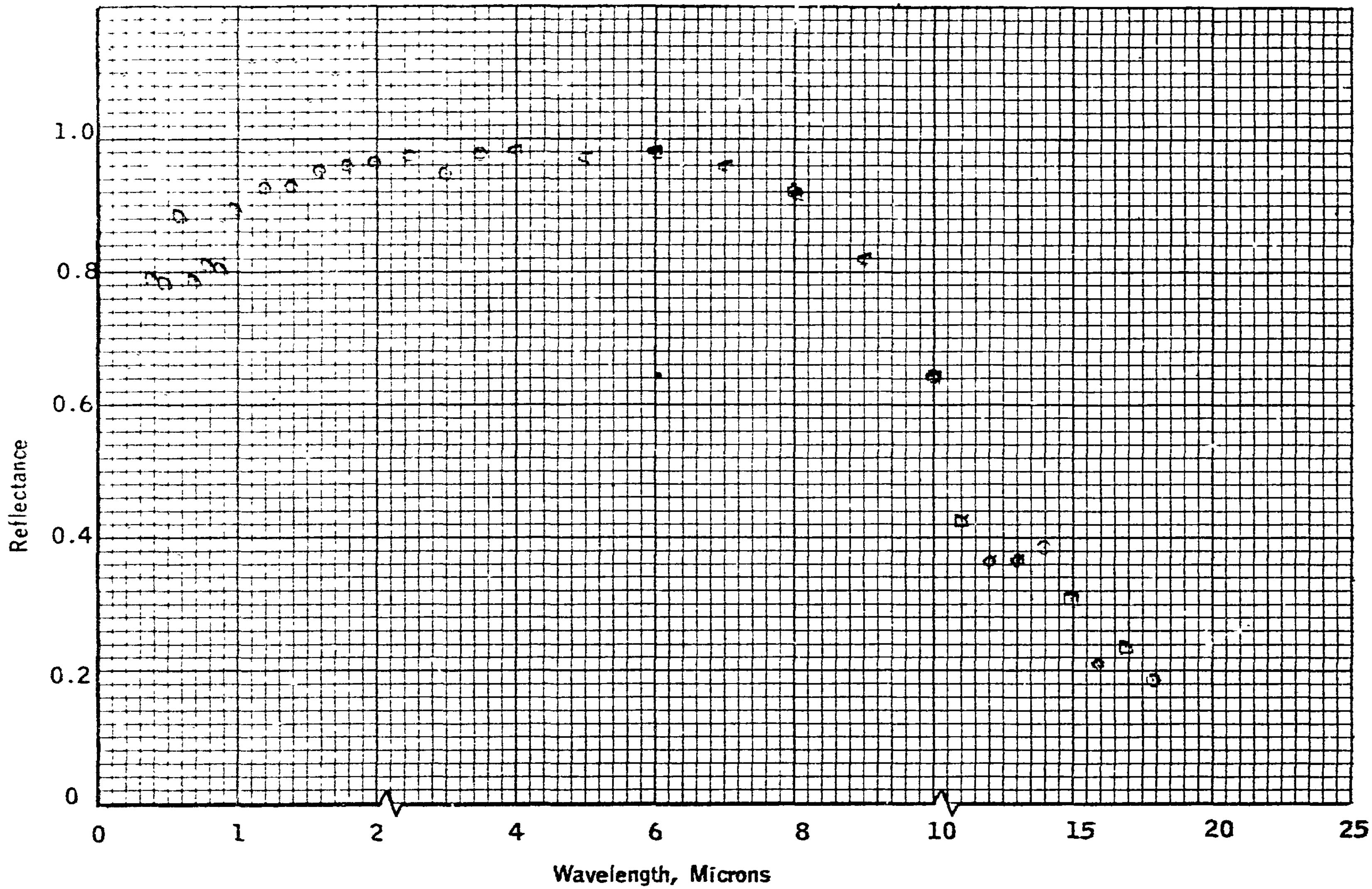


Fig. 38 Normal Spectral Reflectance of Specimen No 92 Temperature RT

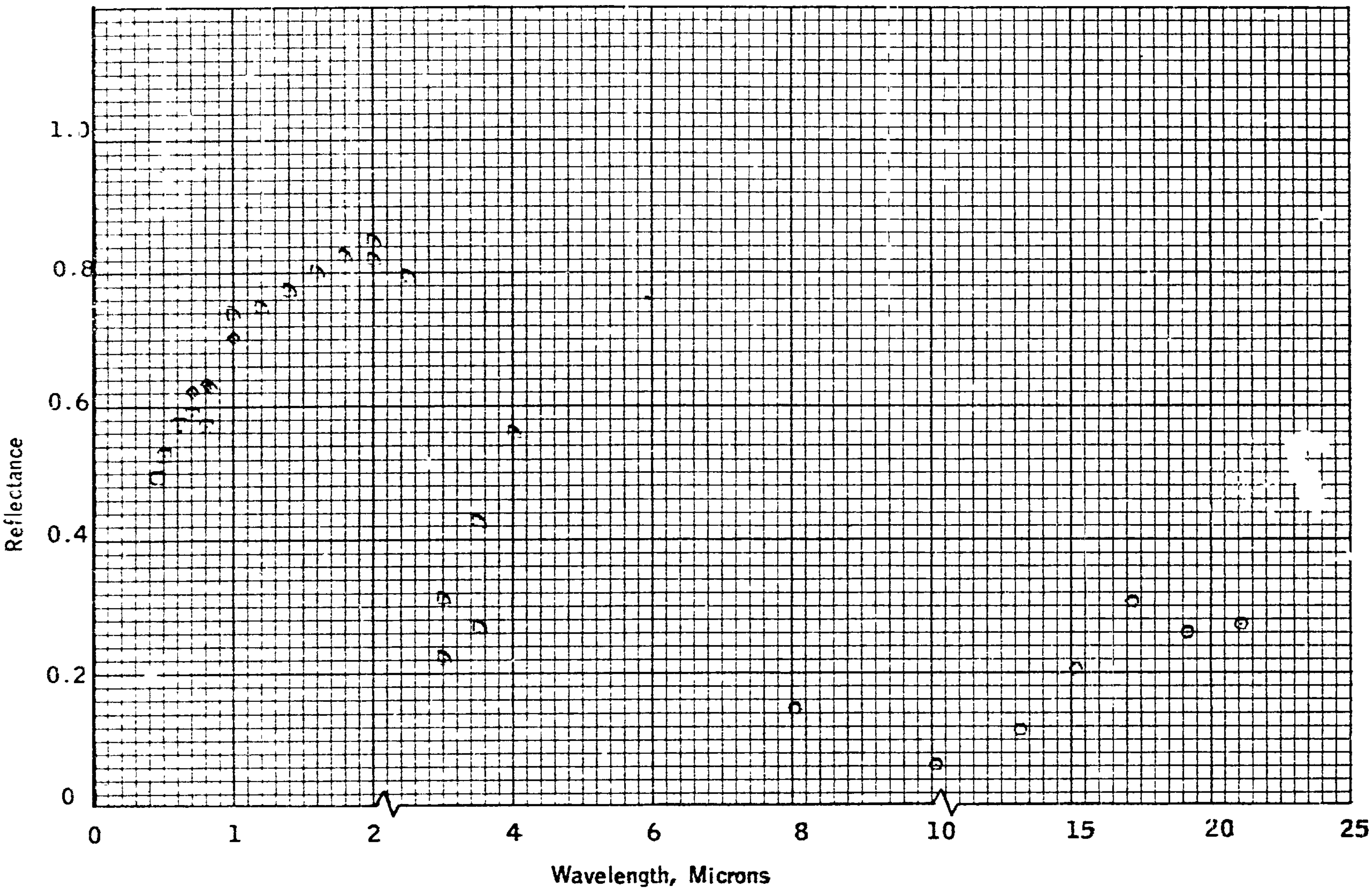


Fig. 39 Normal Spectral Reflectance of Specimen No 63 Temperature RT

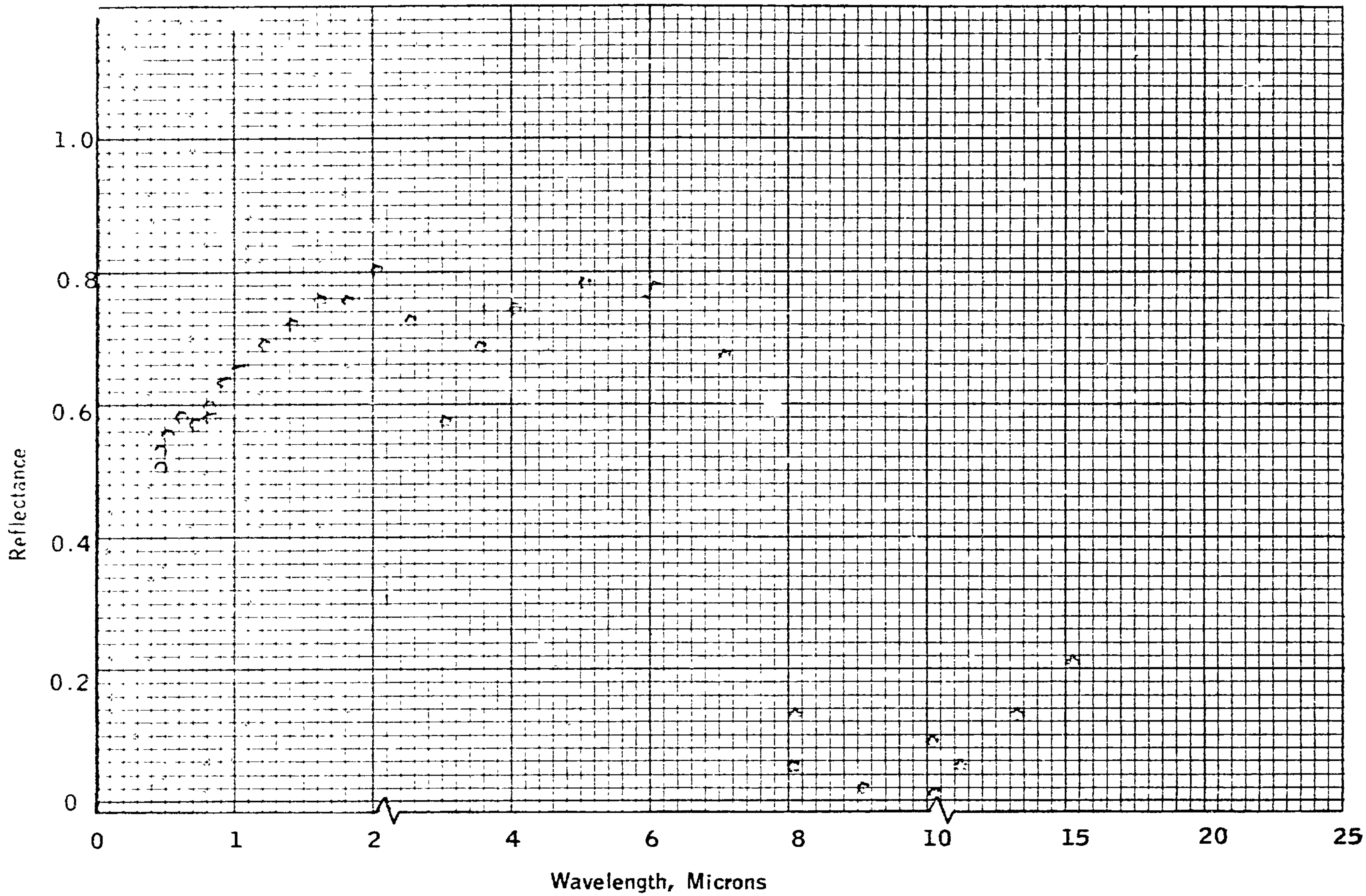


Fig. 40 Normal Spectral Reflectance of Specimen No 63 Temperature 300F

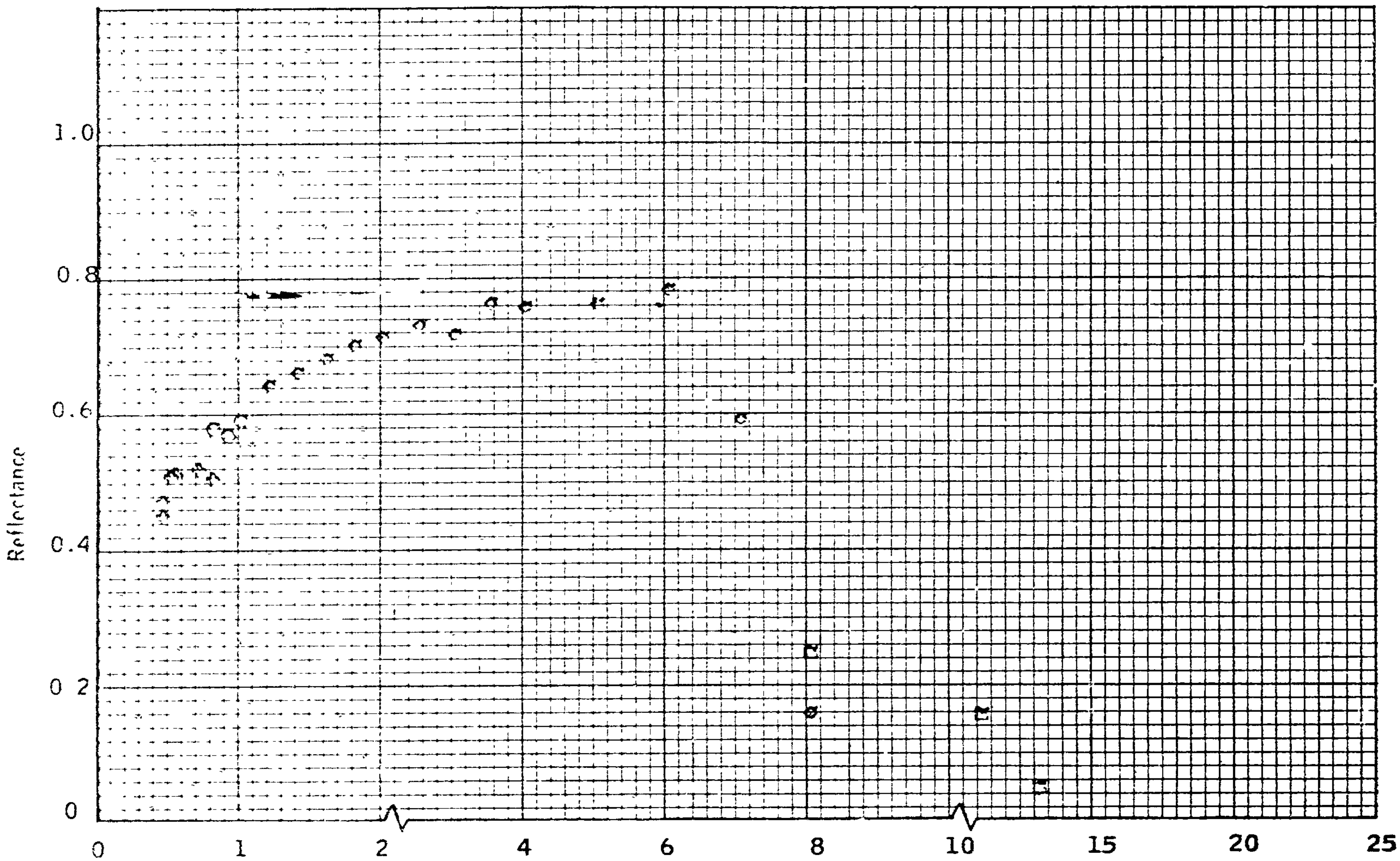


Fig. 41 Normal Spectral Reflectance of Specimen No 63 Temperature 600F

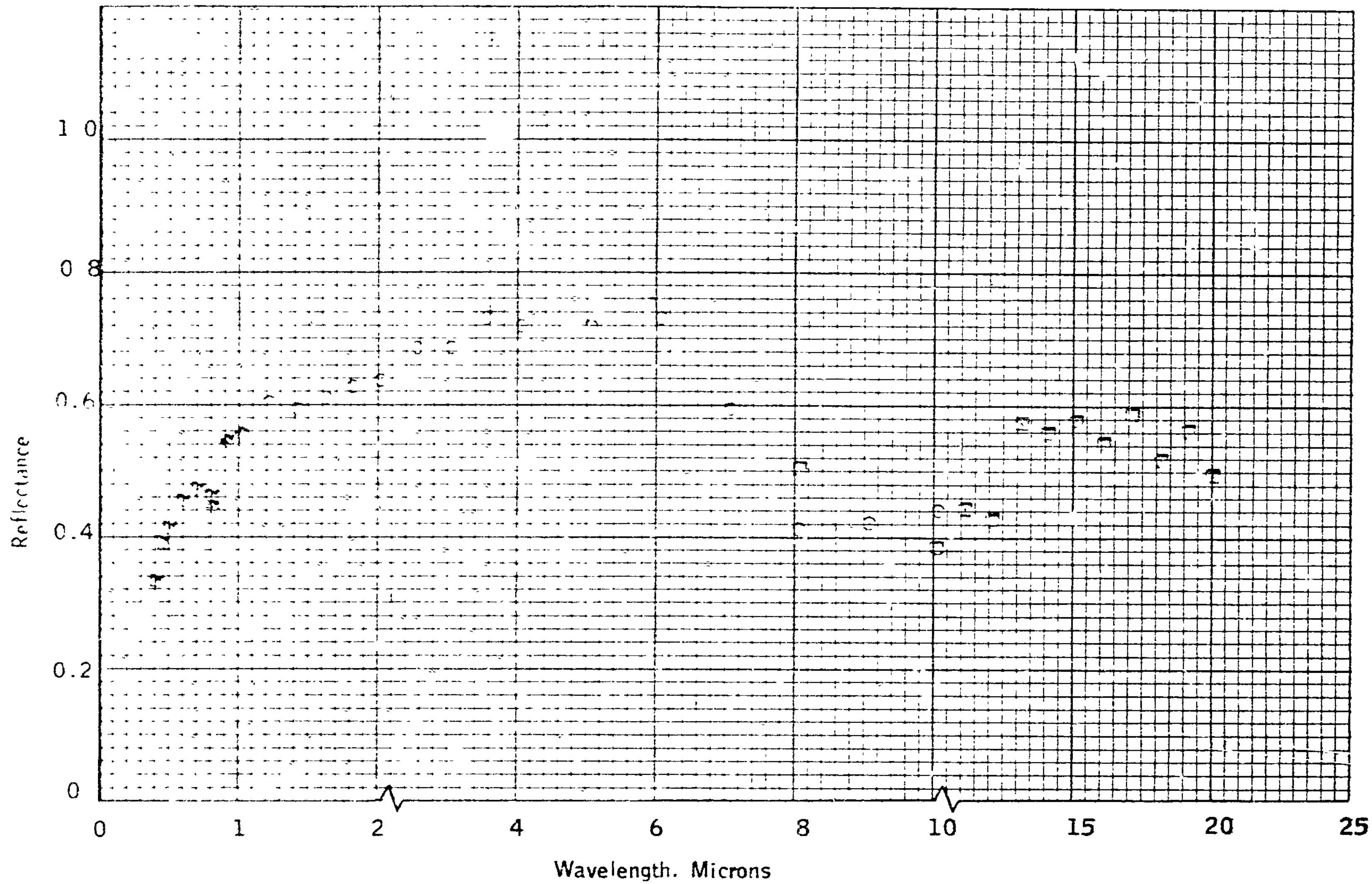


Fig. 42 Normal Spectral Reflectance of Specimen No 63 Temperature 825 F

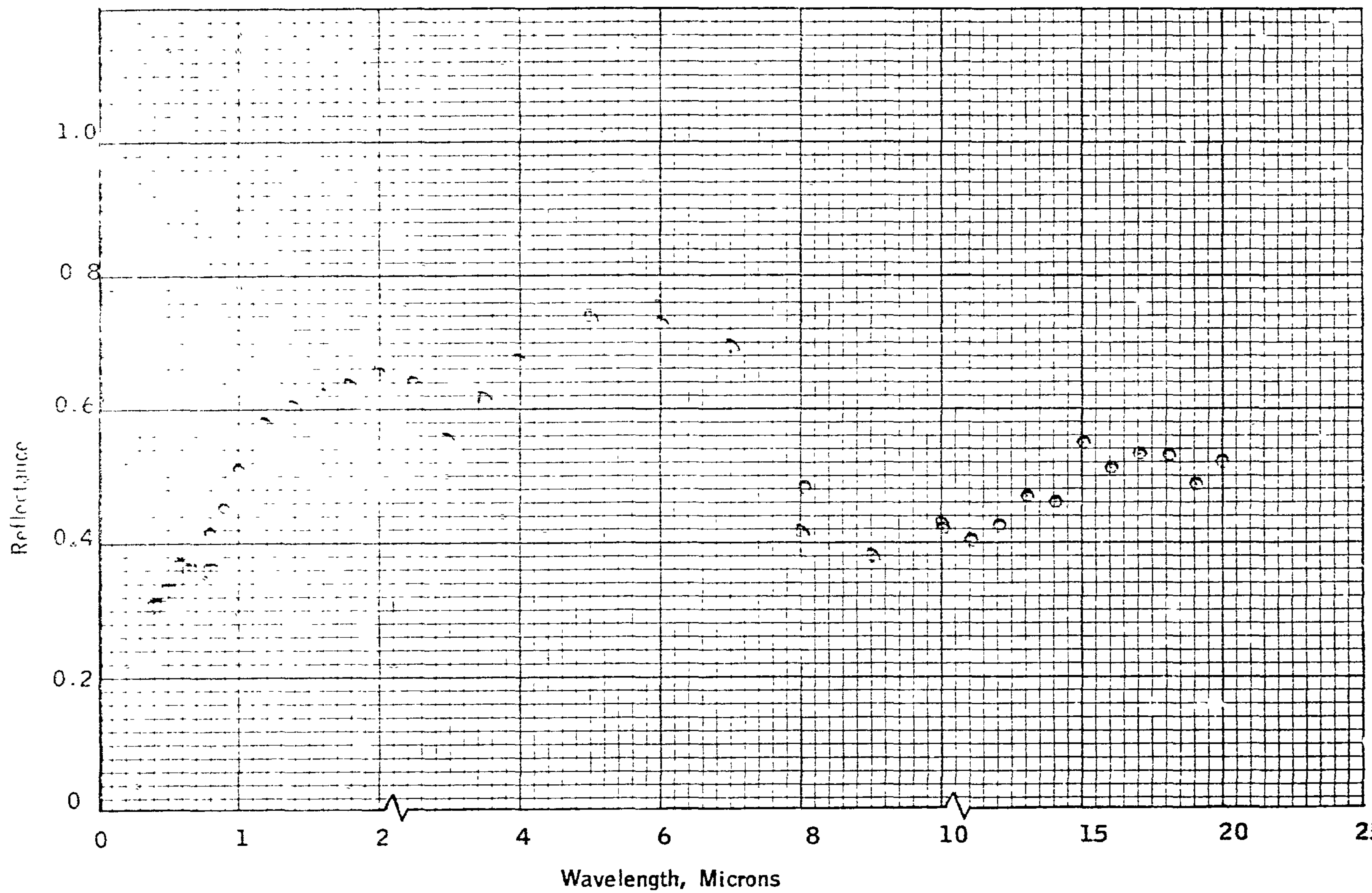


Fig. 43 Normal Spectral Reflectance of Specimen No 63 Temperature RT_f

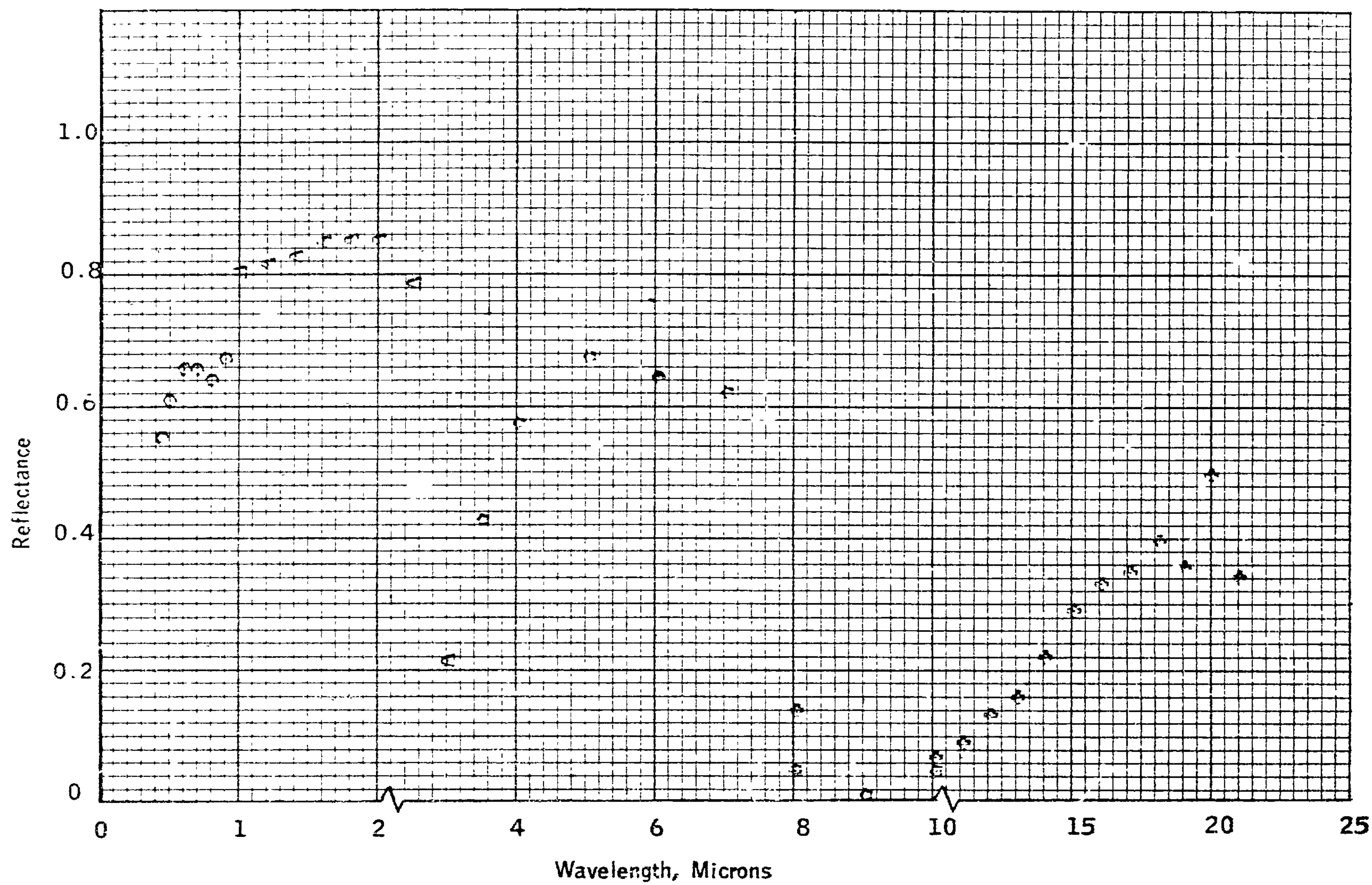


Fig. 44 Normal Spectral Reflectance of Specimen No 64 Temperature RT

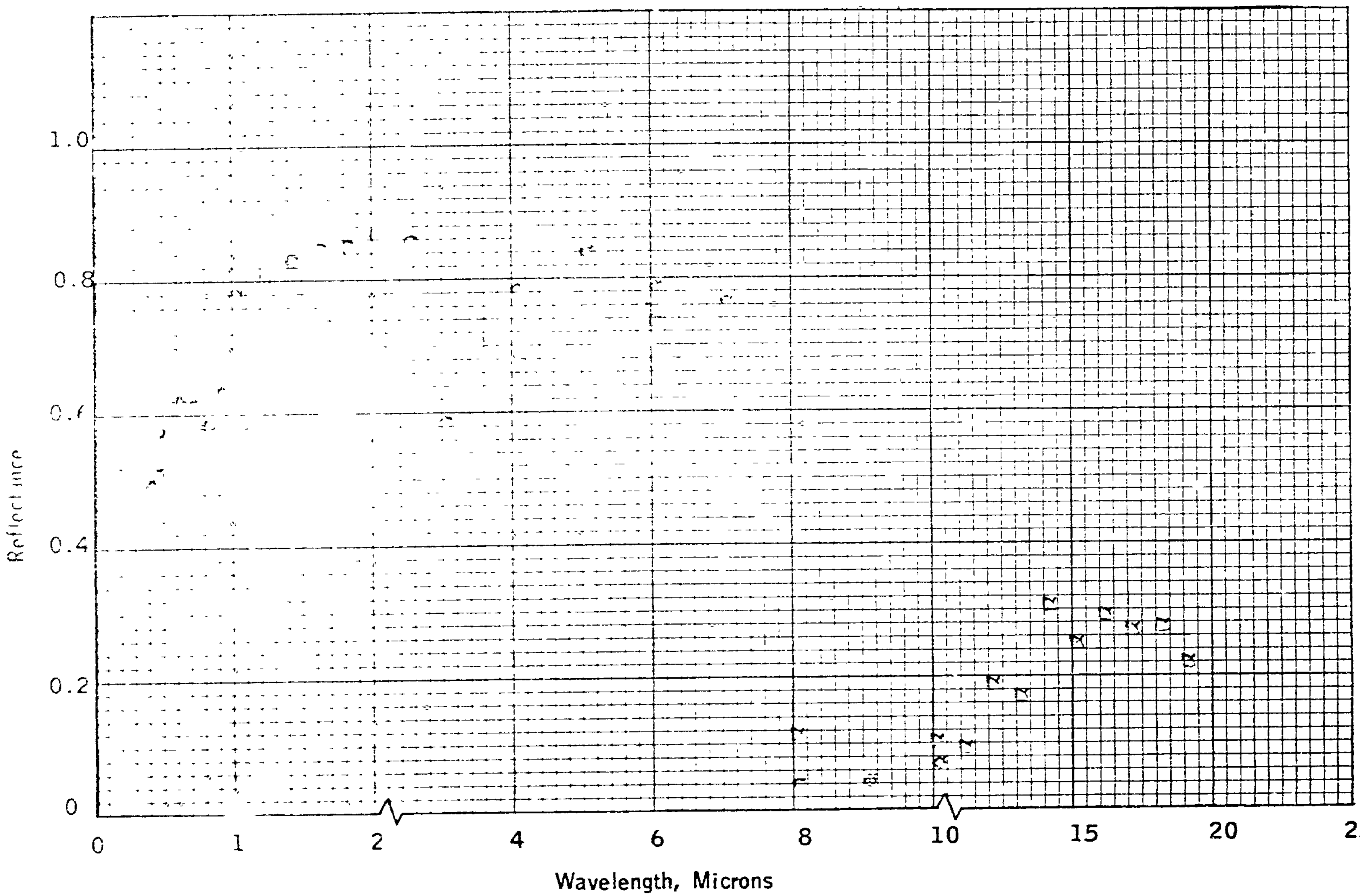


Fig. 45 Normal Spectral Reflectance of Specimen No 65 Temperature RT

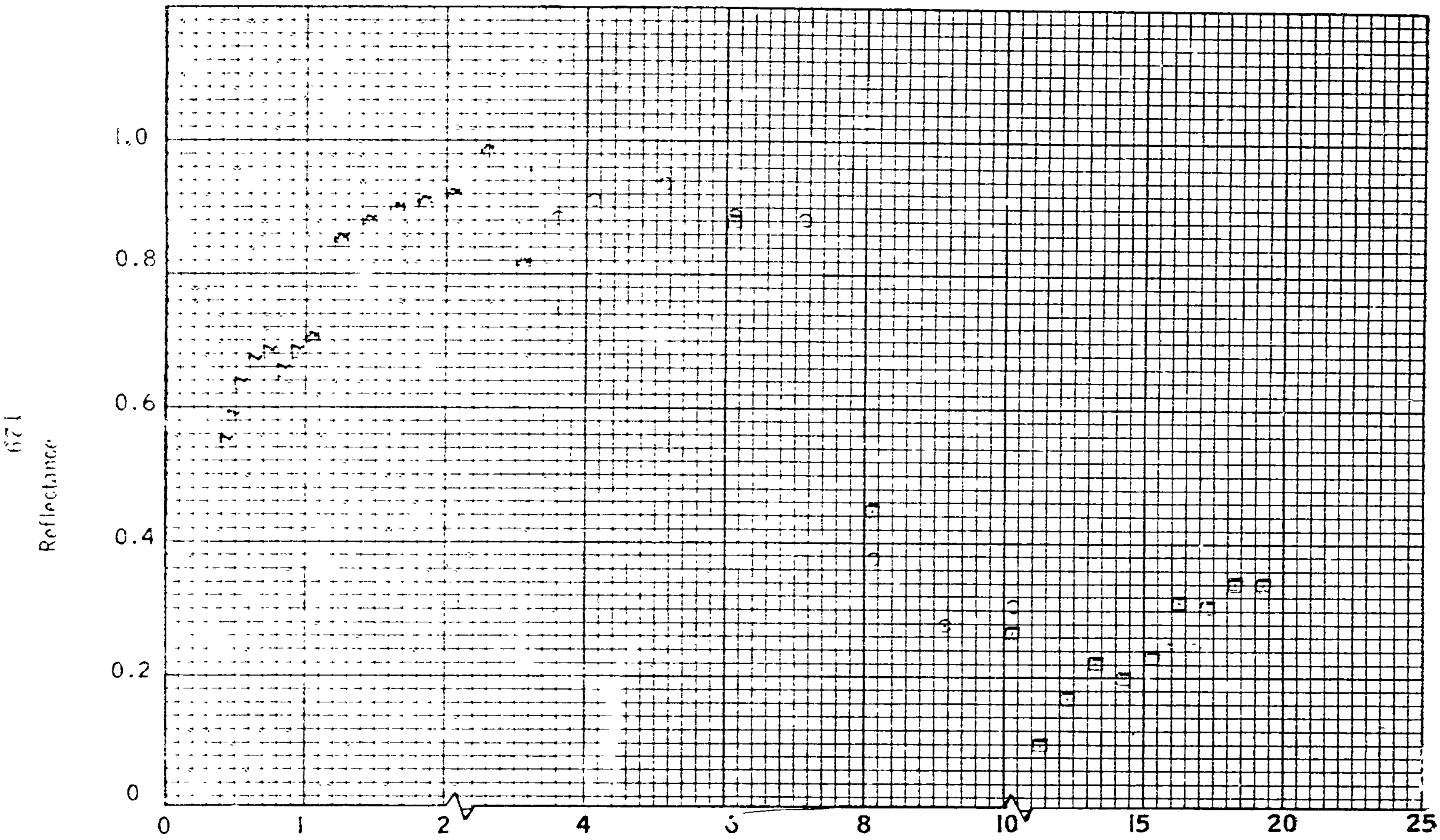


Fig. 46 Normal Spectral Reflectance of Specimen No 66 Temperature RT

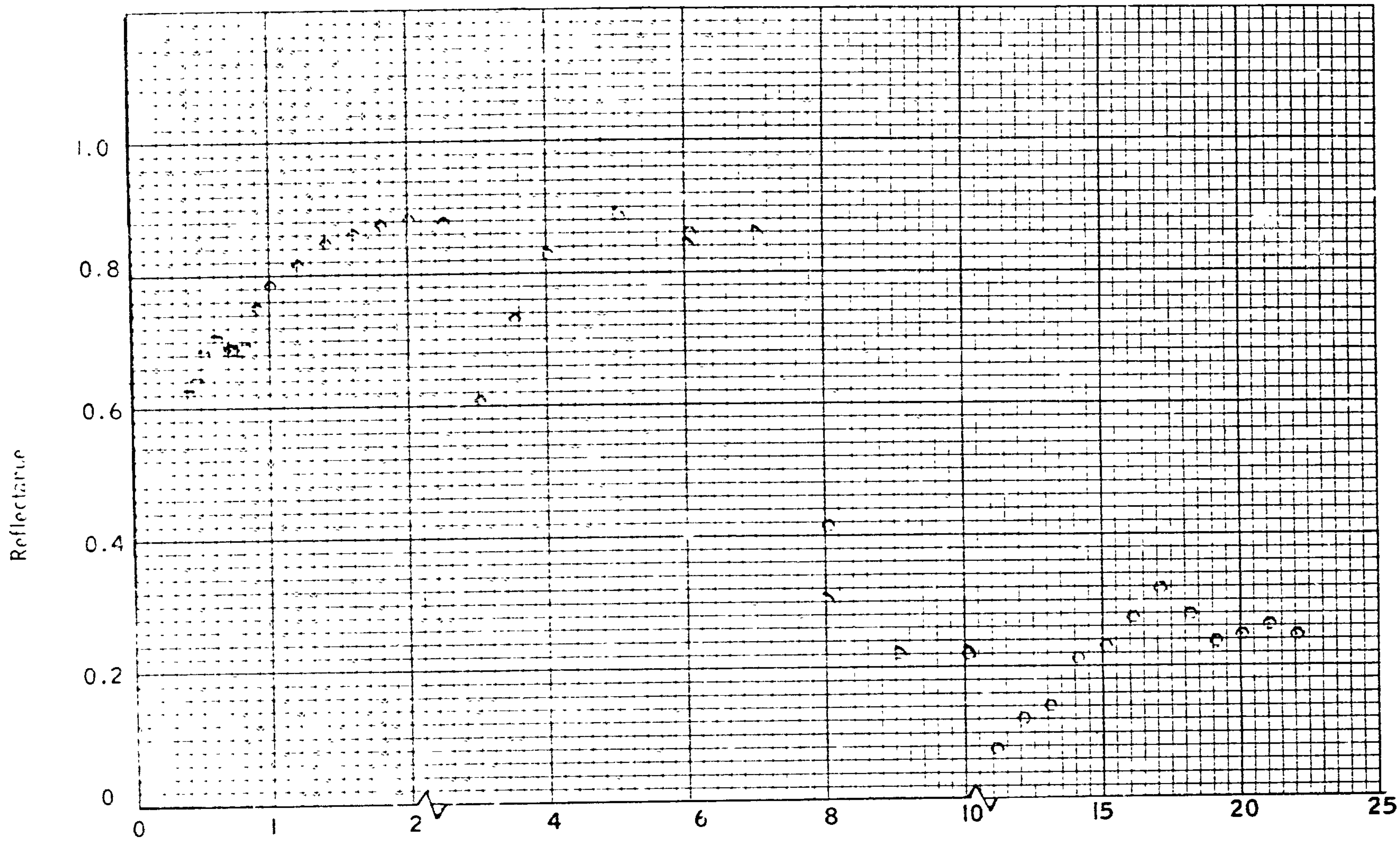


Fig. 47 Normal Spectral Reflectance of Specimen No 73 Temperature RT

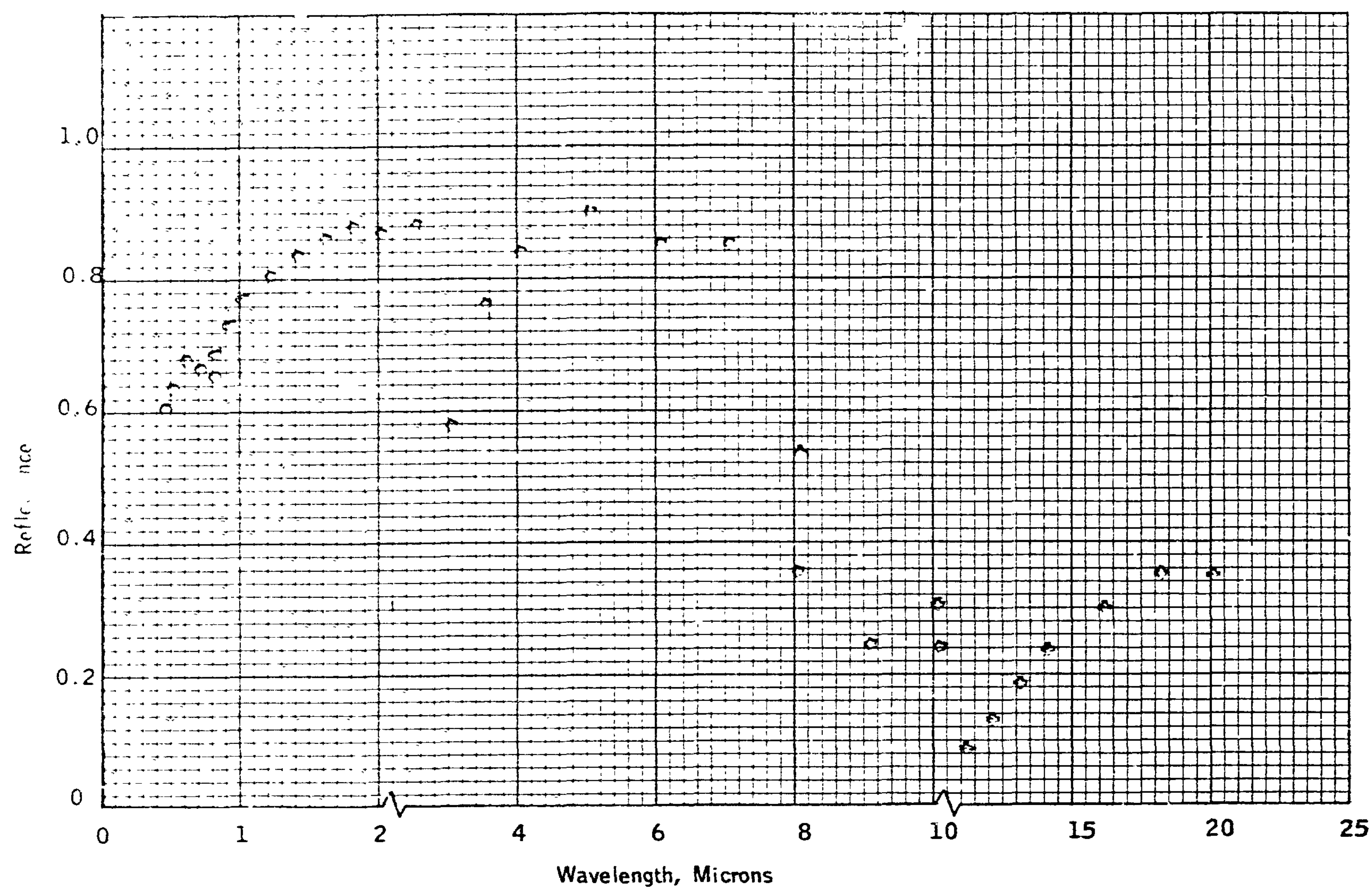


Fig. 48 Normal Spectral Reflectance of Specimen No 74 Temperature RT

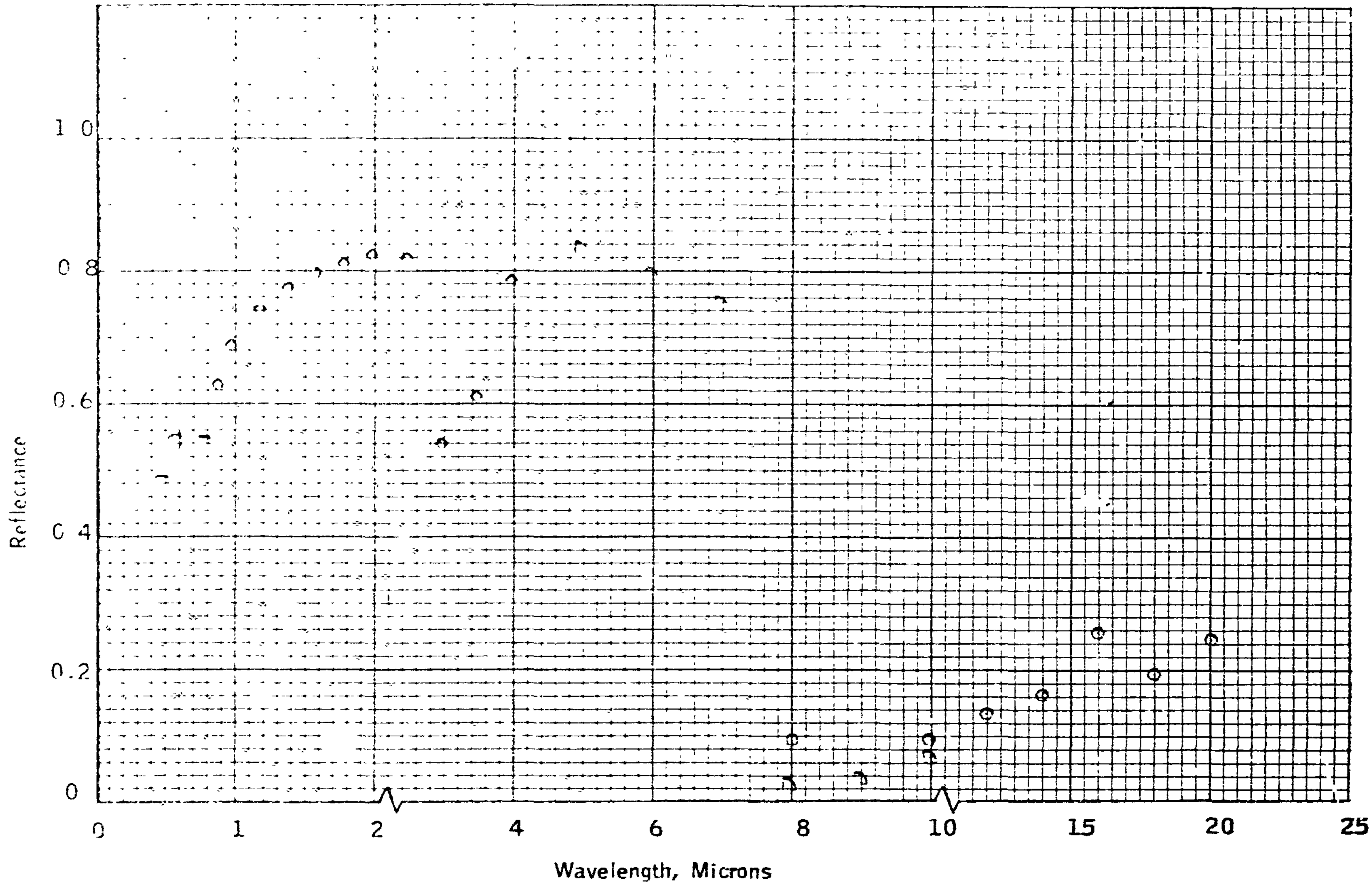


Fig. 49 Normal Spectral Reflectance of Specimen No 77 Temperature RT

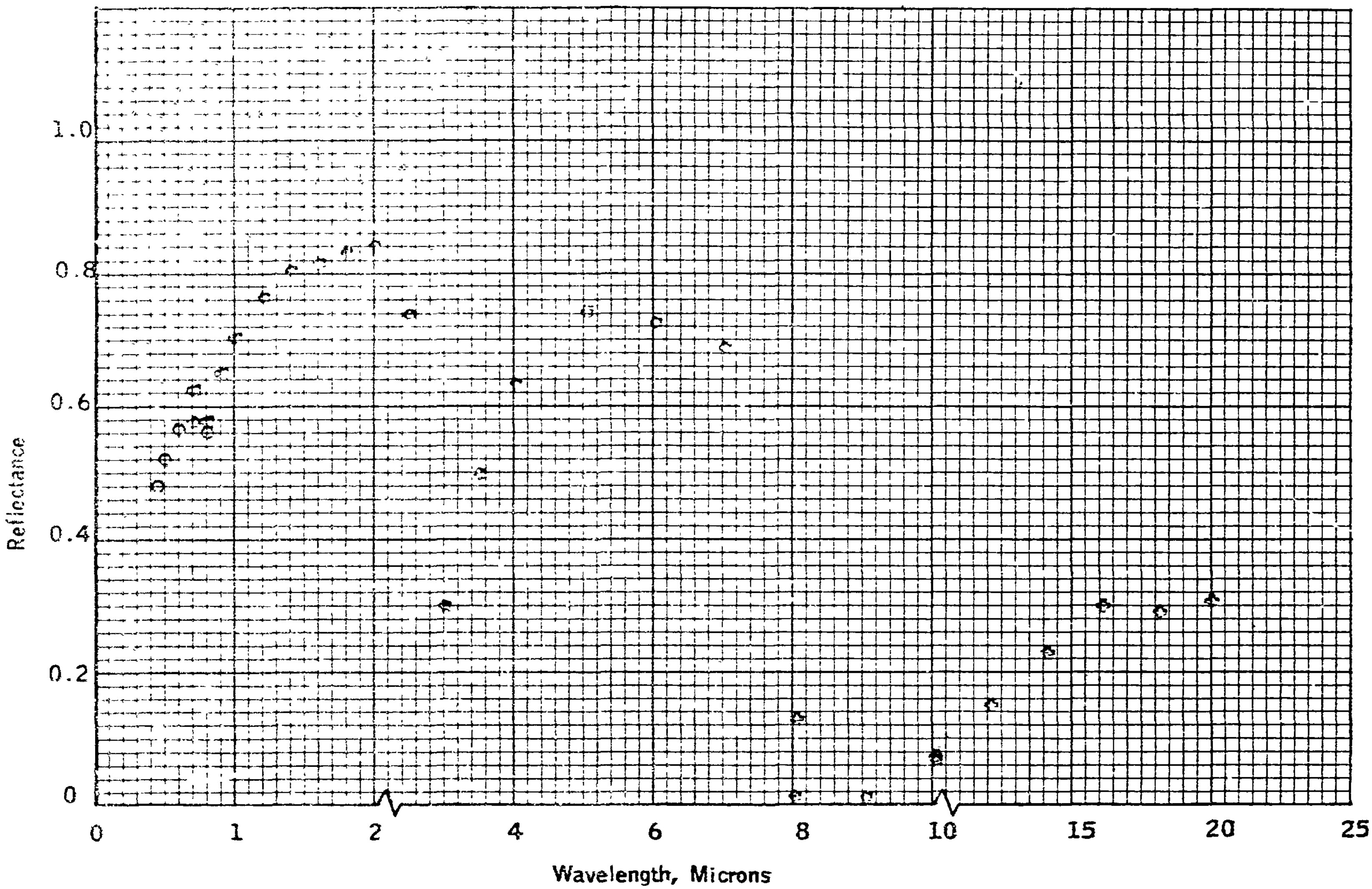


Fig. 50 Normal Spectral Reflectance of Specimen No 78 Temperature RT

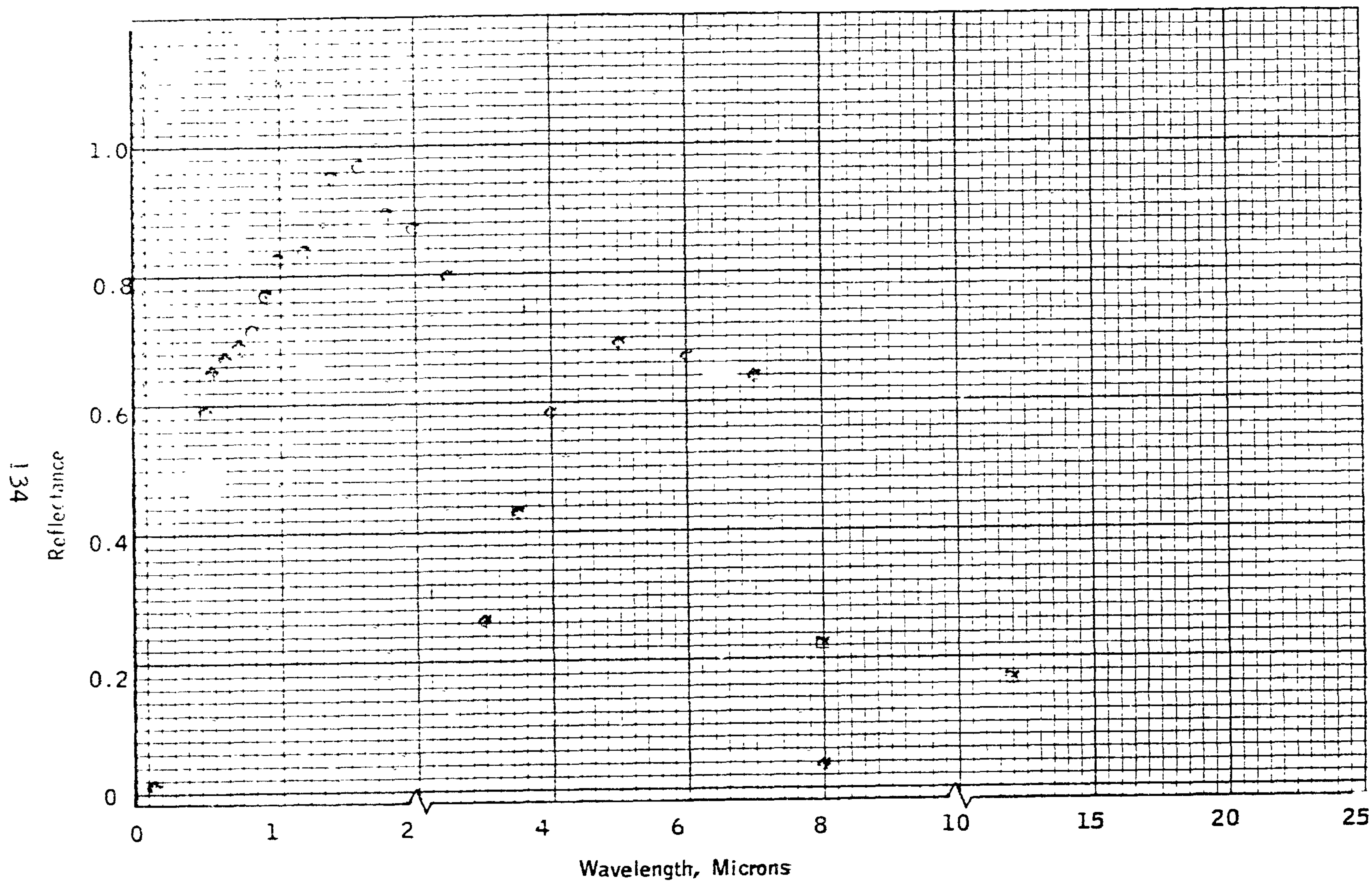


Fig. 51 Normal Spectral Reflectance of Specimen No 120 Temperature RT

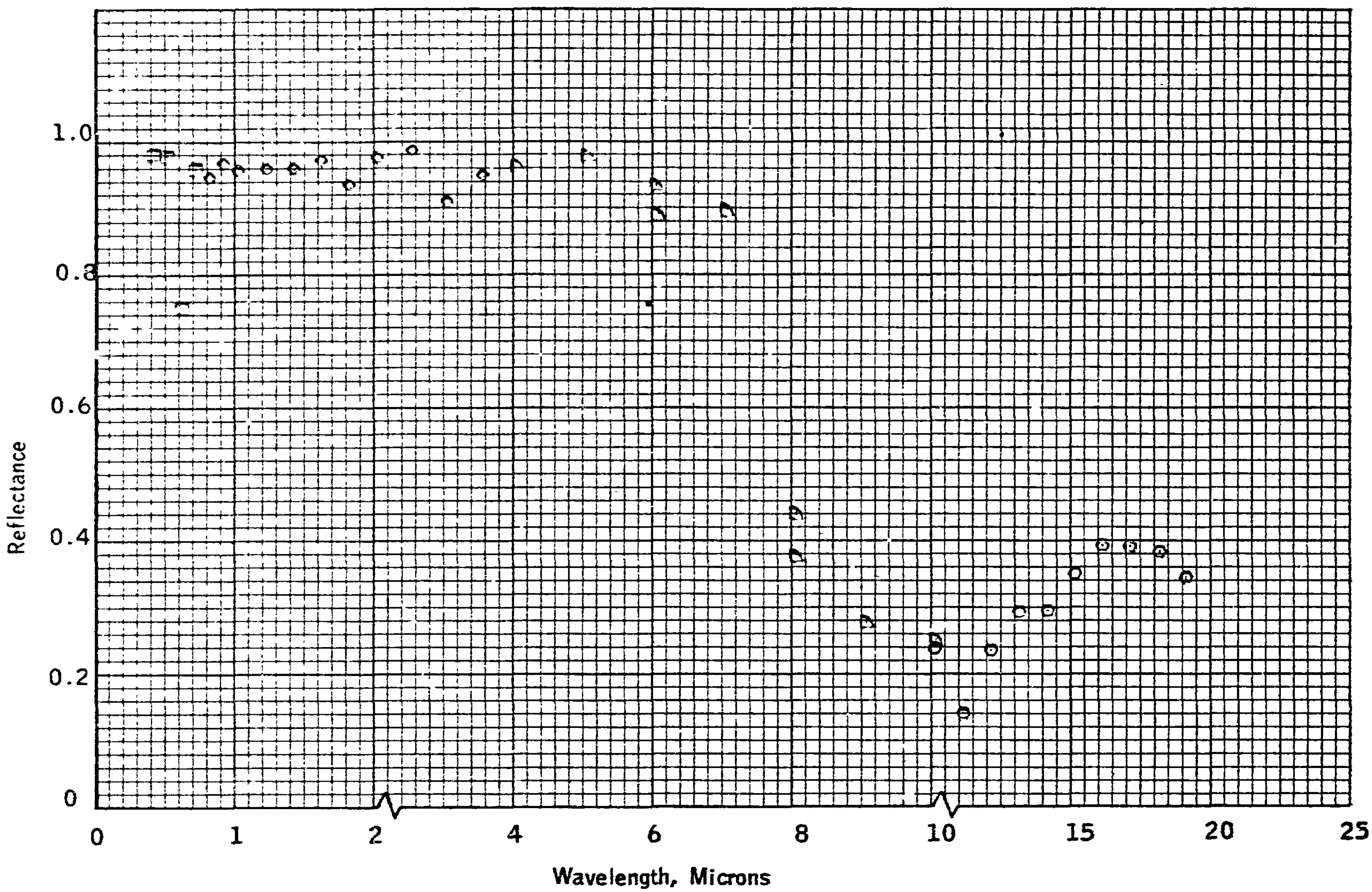


Fig. 52 Normal Spectral Reflectance of Specimen No 67 Temperature RT

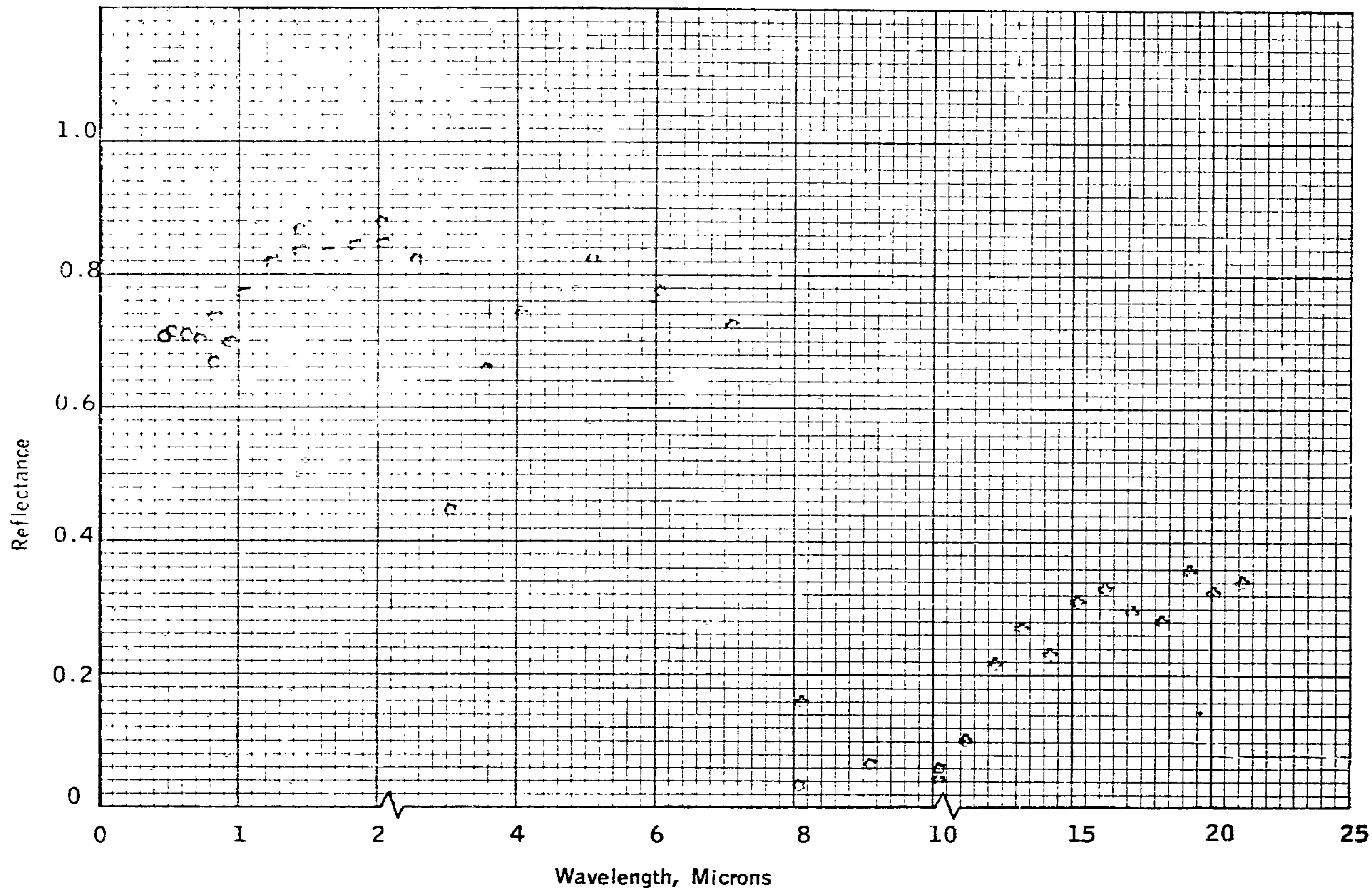


Fig. 53 Normal Spectral Reflectance of Specimen No 68 Temperature RT, HT-800F

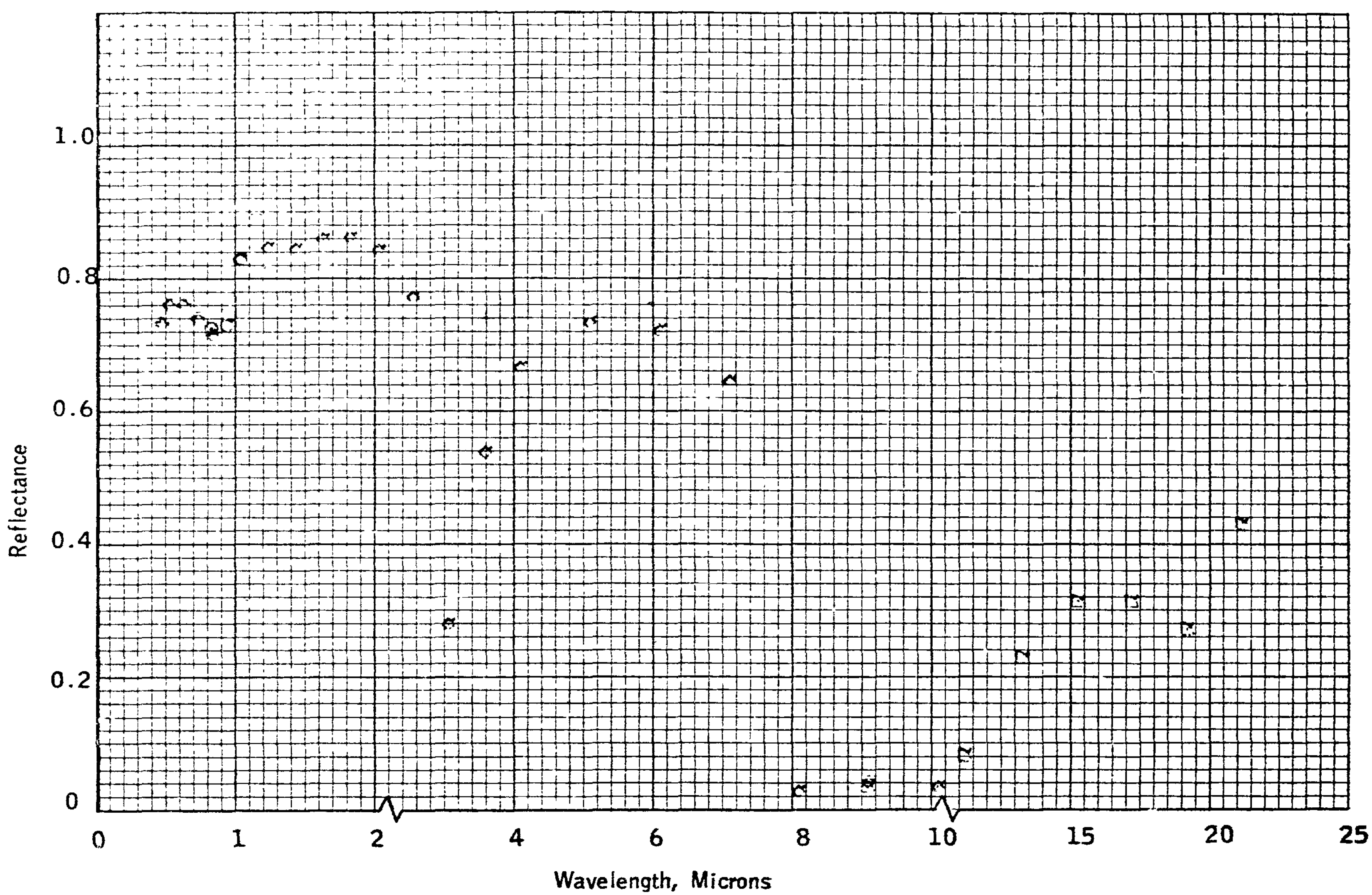


Fig. 54 Normal Spectral Reflectance of Specimen No 69 Temperature RT

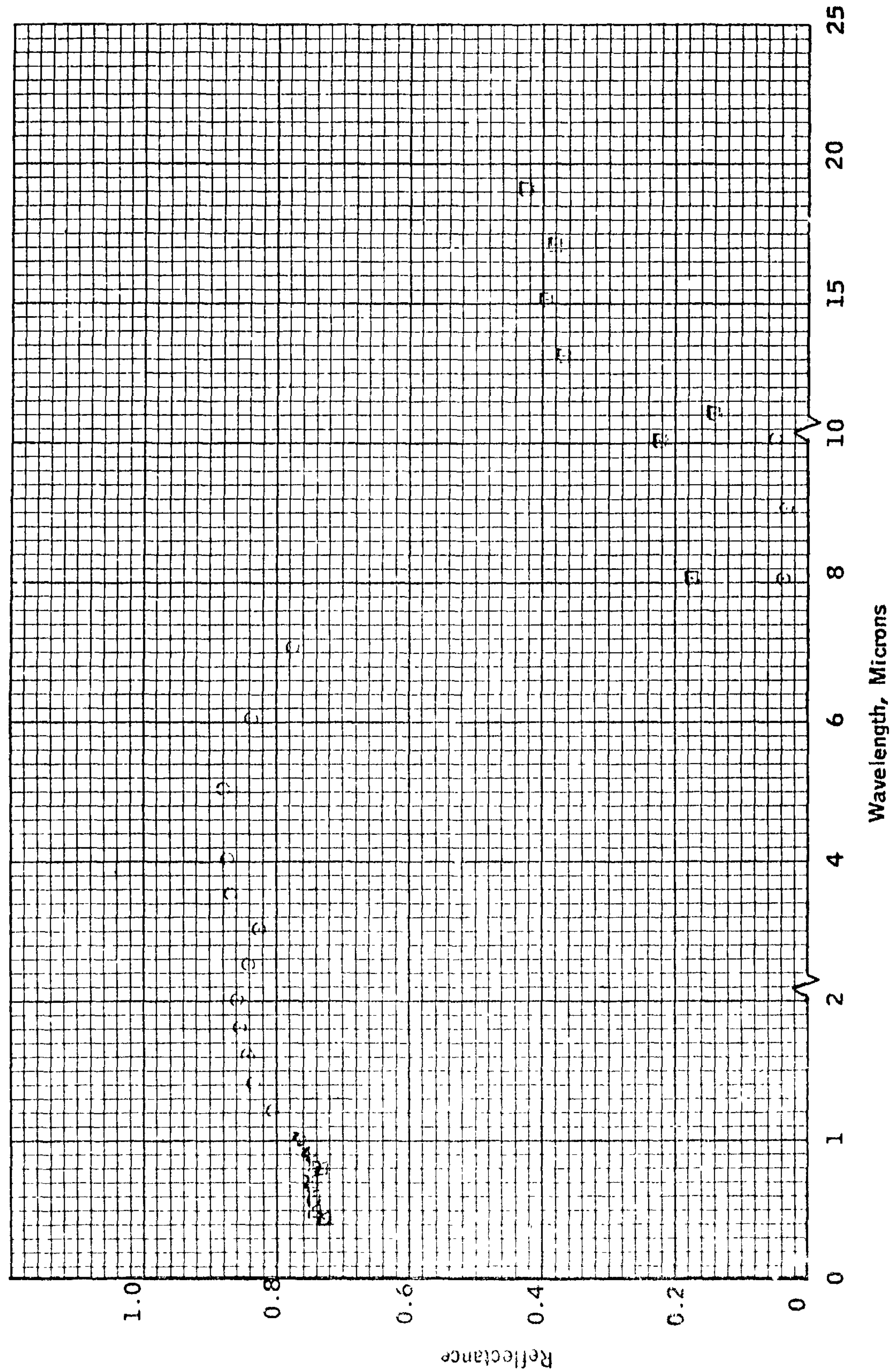


Fig. 55 Normal Spectral Reflectance of Specimen No 69 Temperature 600F

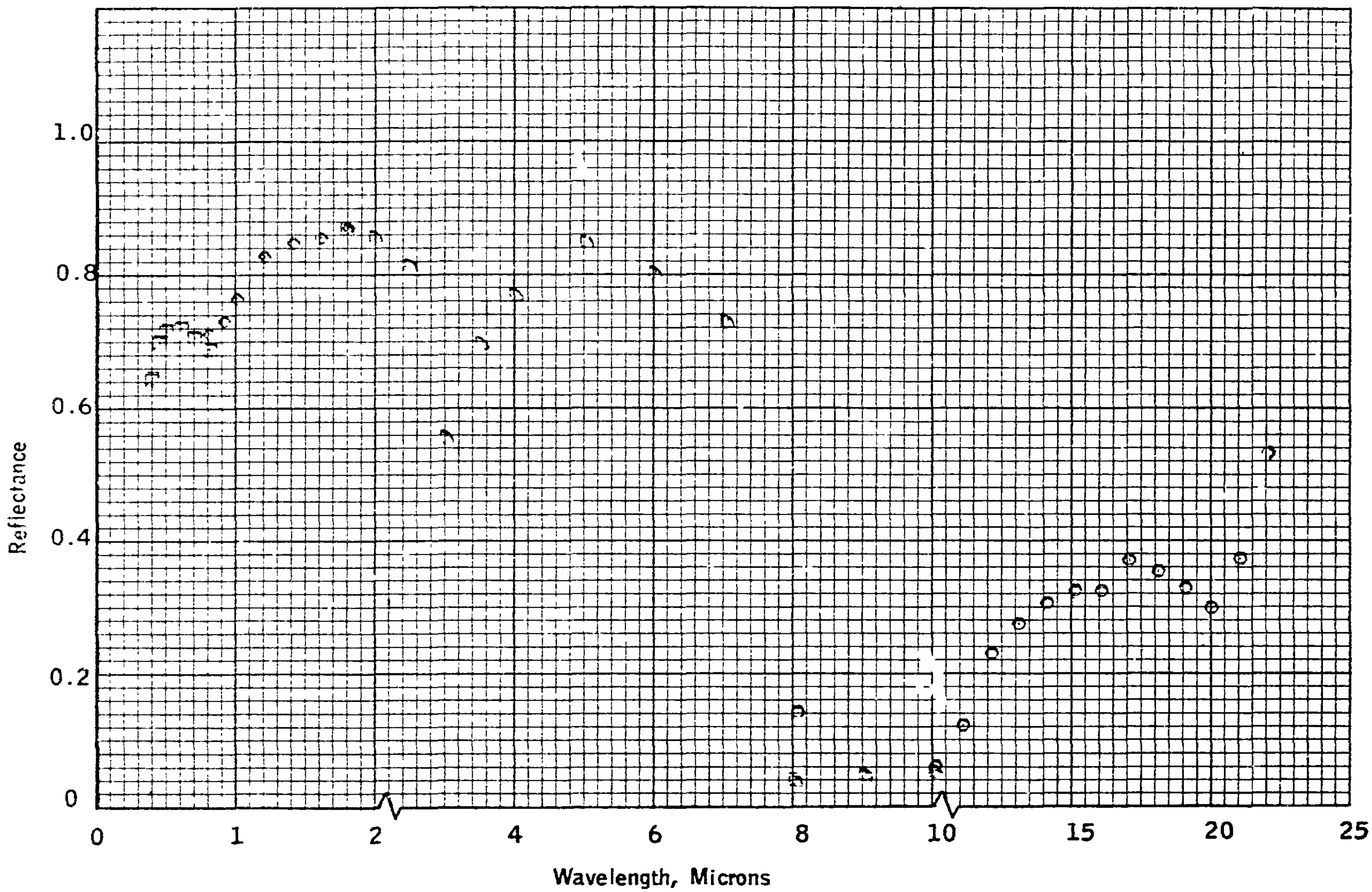


Fig. 56 Normal Spectral Reflectance of Specimen No 69 Temperature RT_f

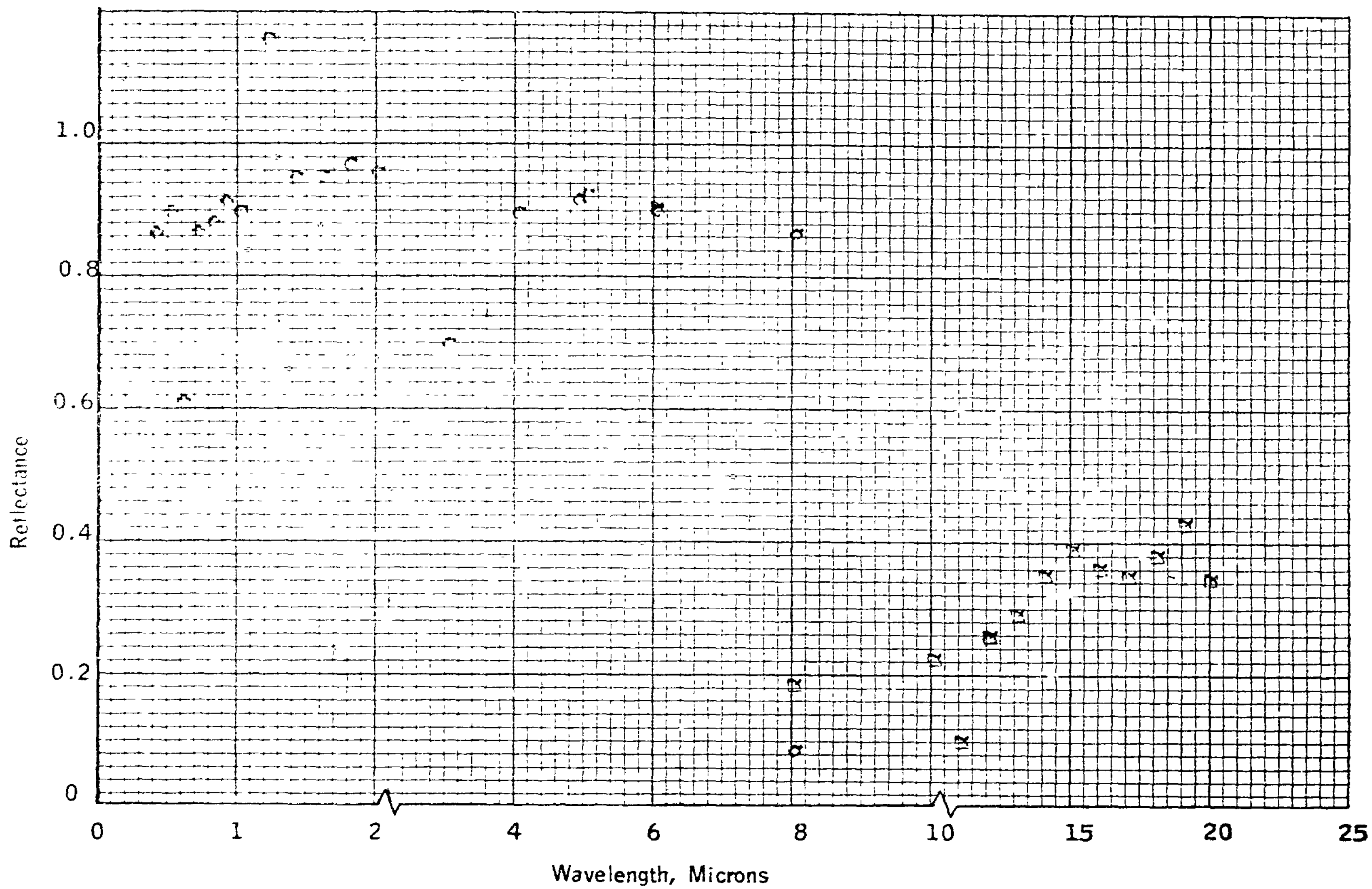


Fig. 57   Normal Spectral Reflectance of Specimen No 71   Temperature RT

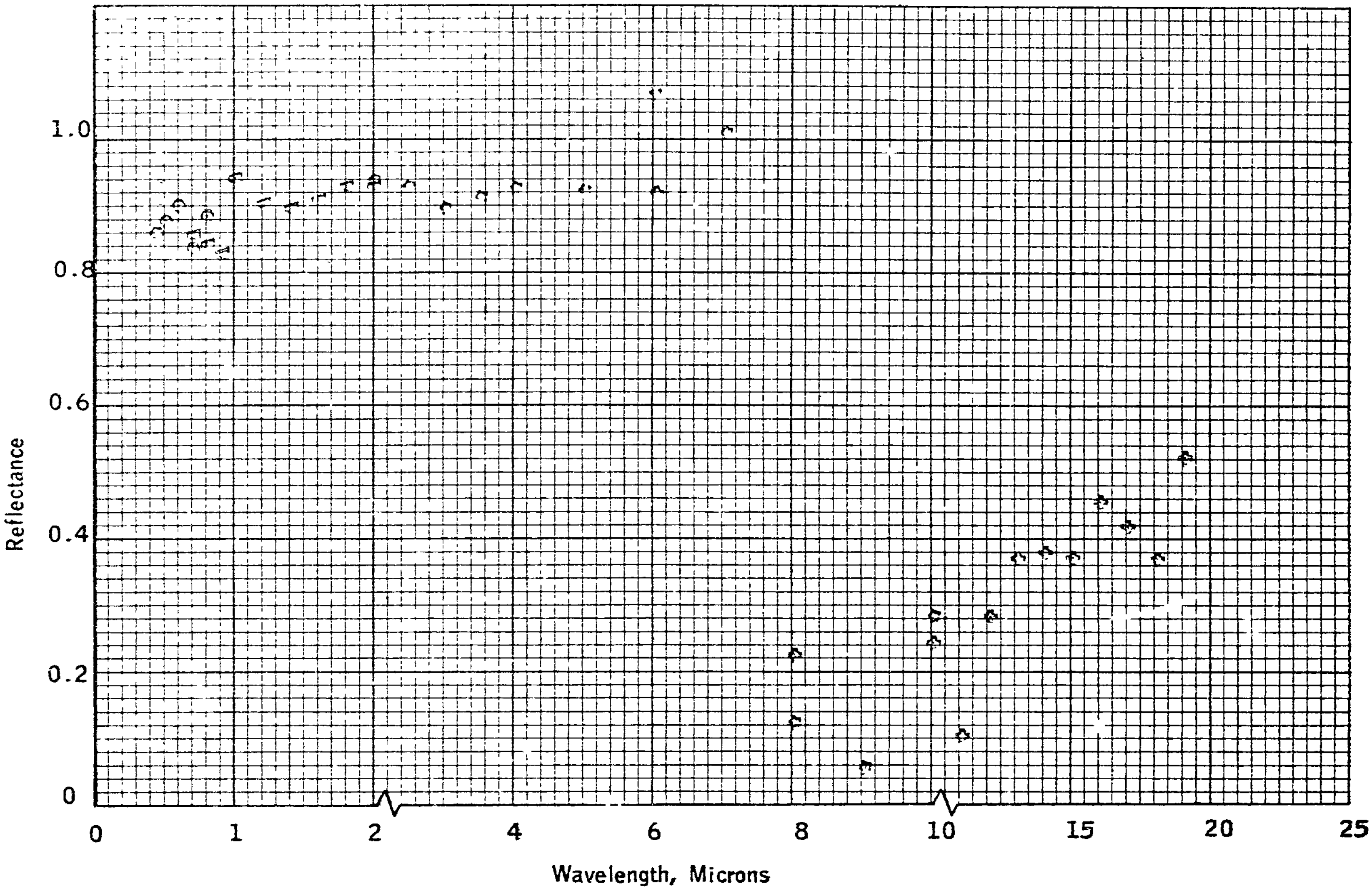


Fig. 58 Normal Spectral Reflectance of Specimen No 71 Temperature 300F

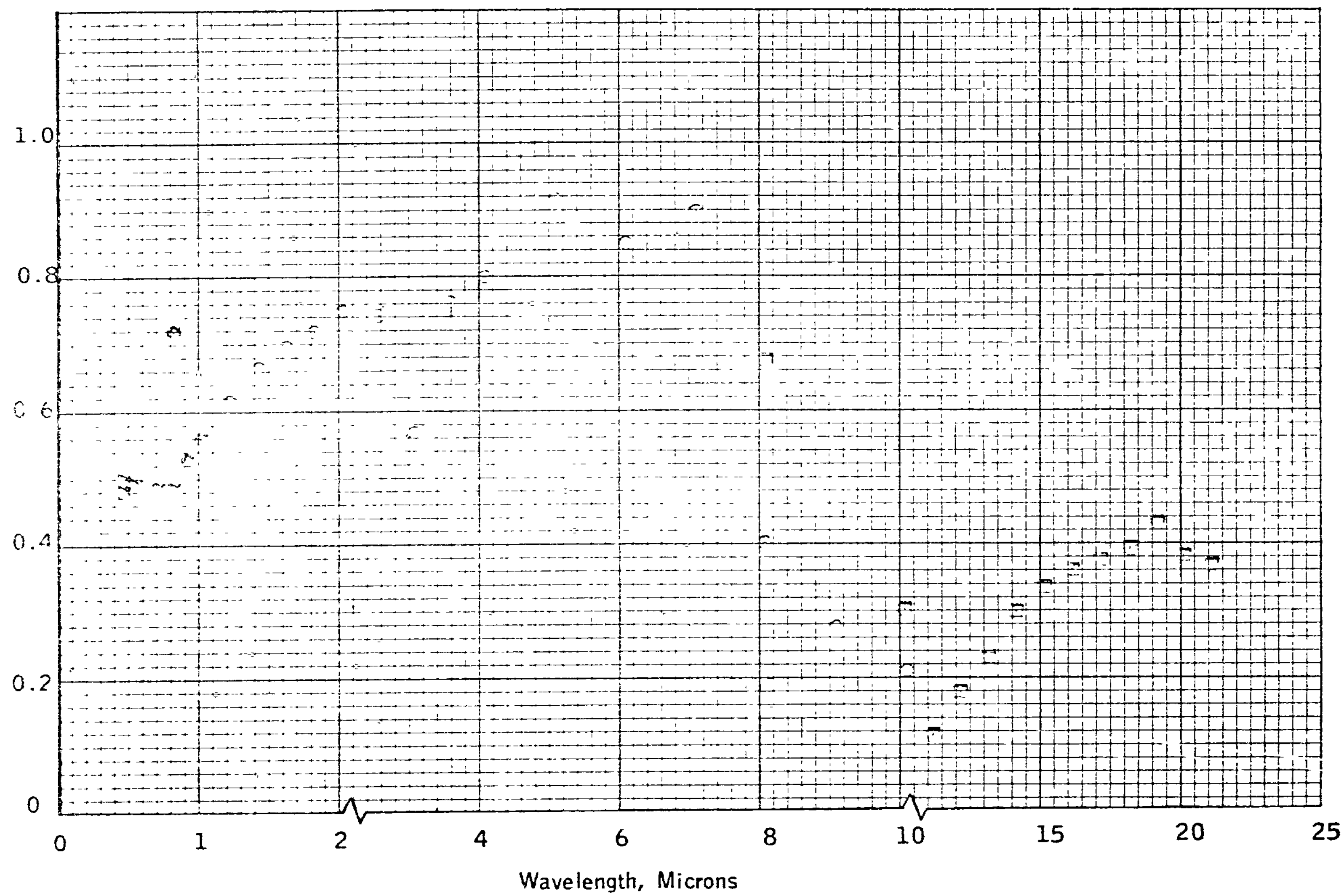


Fig. 59 Normal Spectral Reflectance of Specimen No 72 Temperature RT

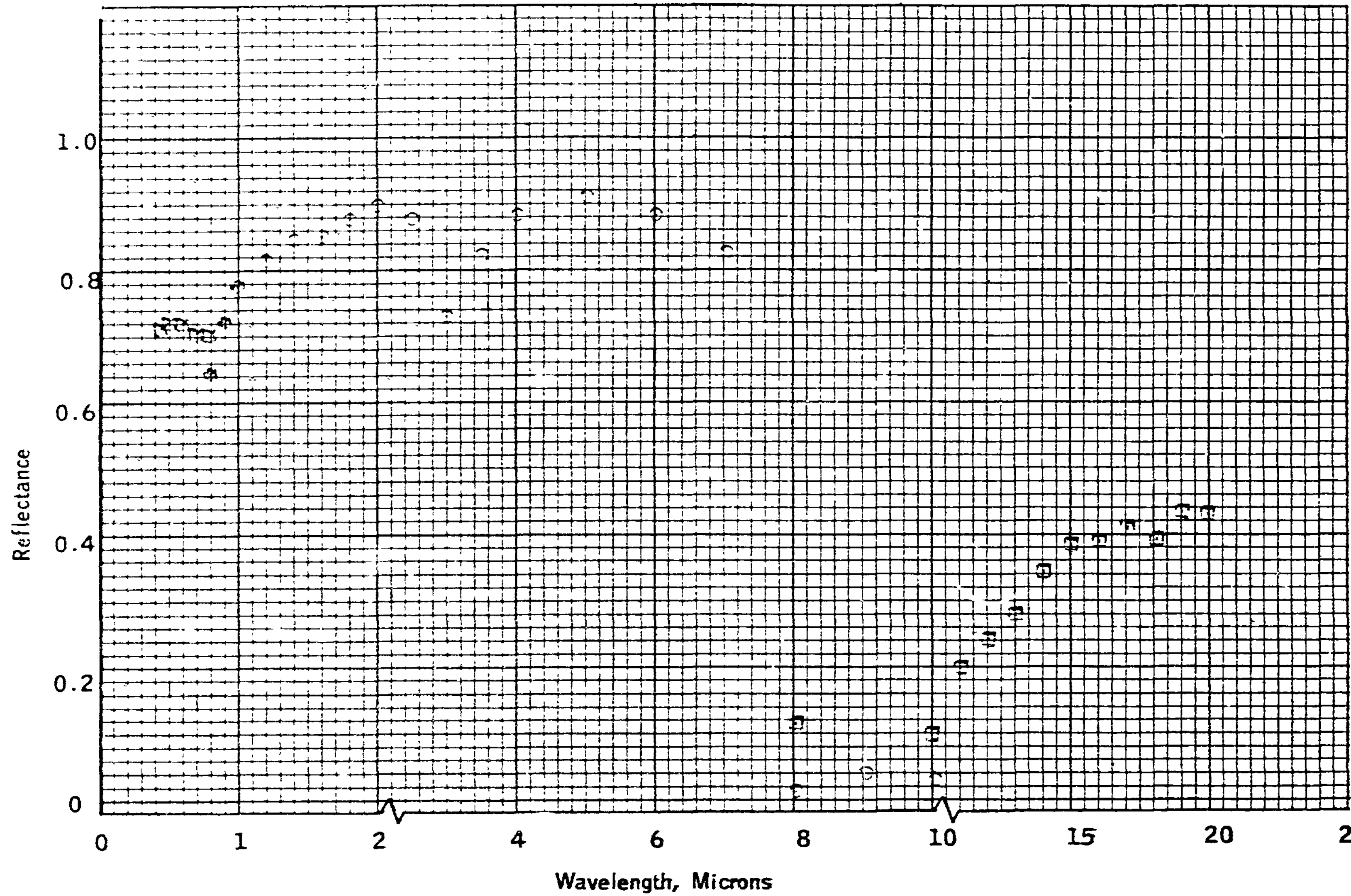


Fig. 6C Normal Spectral Reflectance of Specimen No 80 Temperature RT

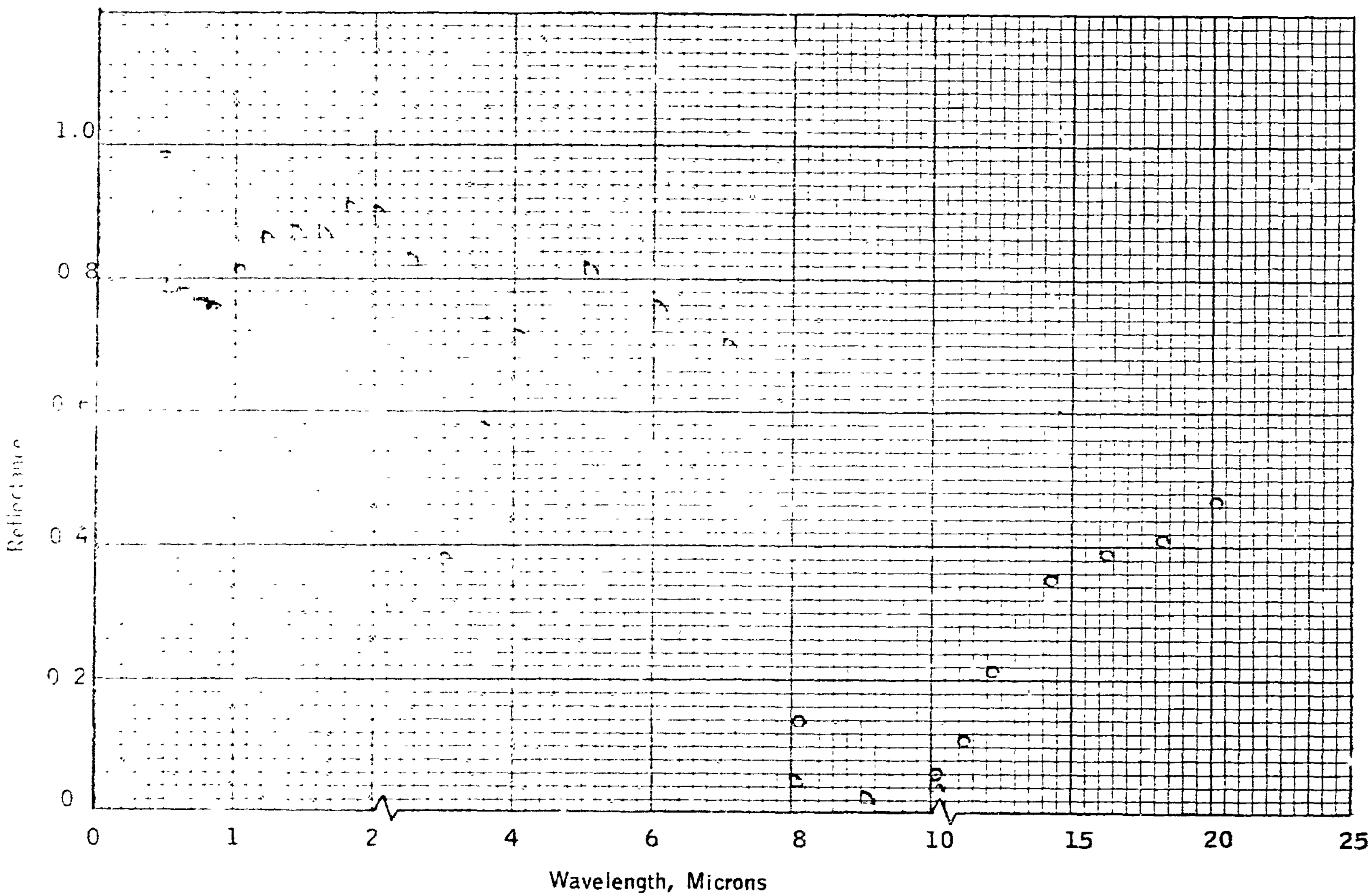


Fig. 3.1 Normal Spectral Reflectance of Specimen No 31 Temperature RT

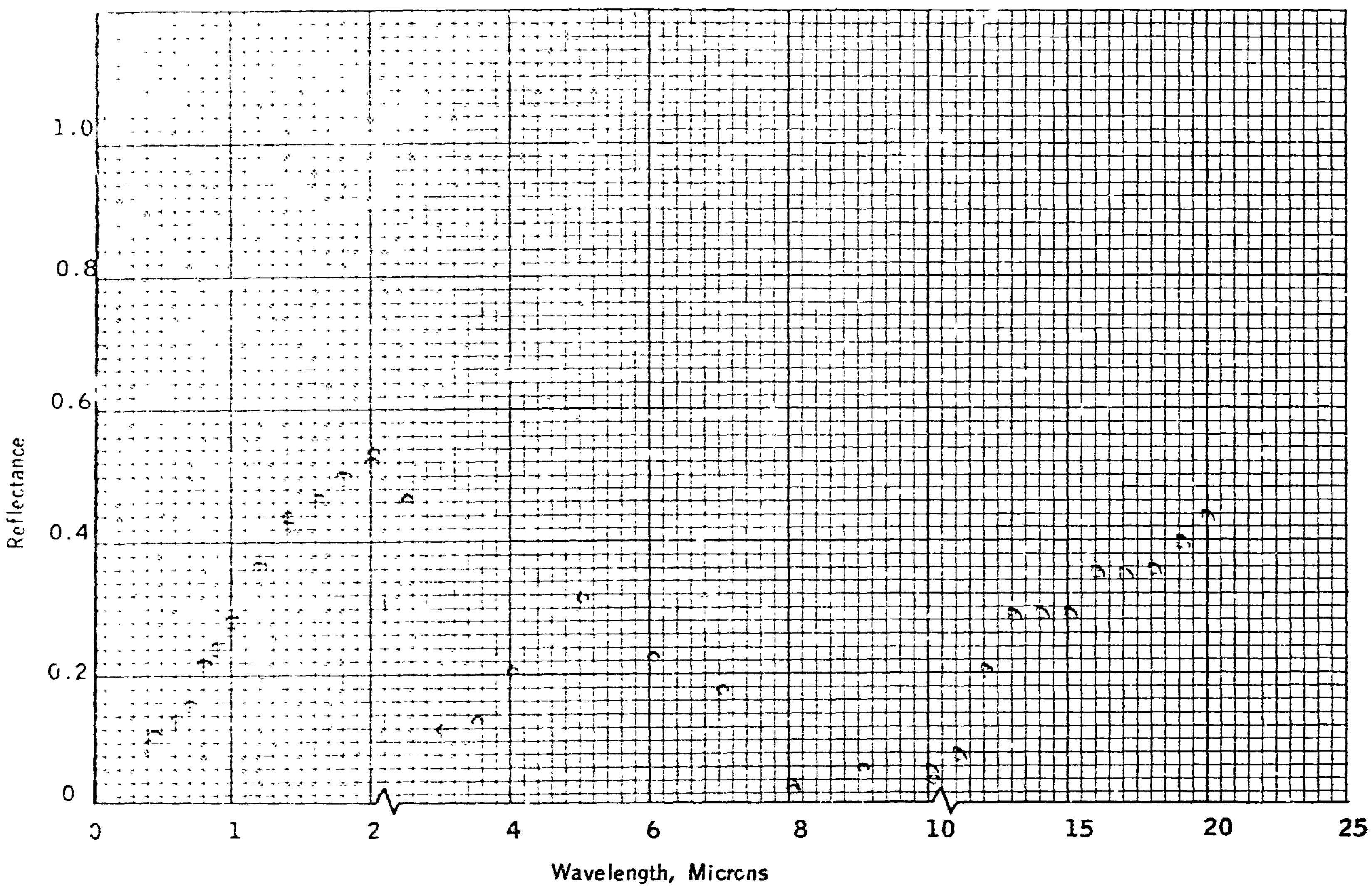


Fig. 62 Normal Spectral Reflectance of Specimen No 11 Temperature RT

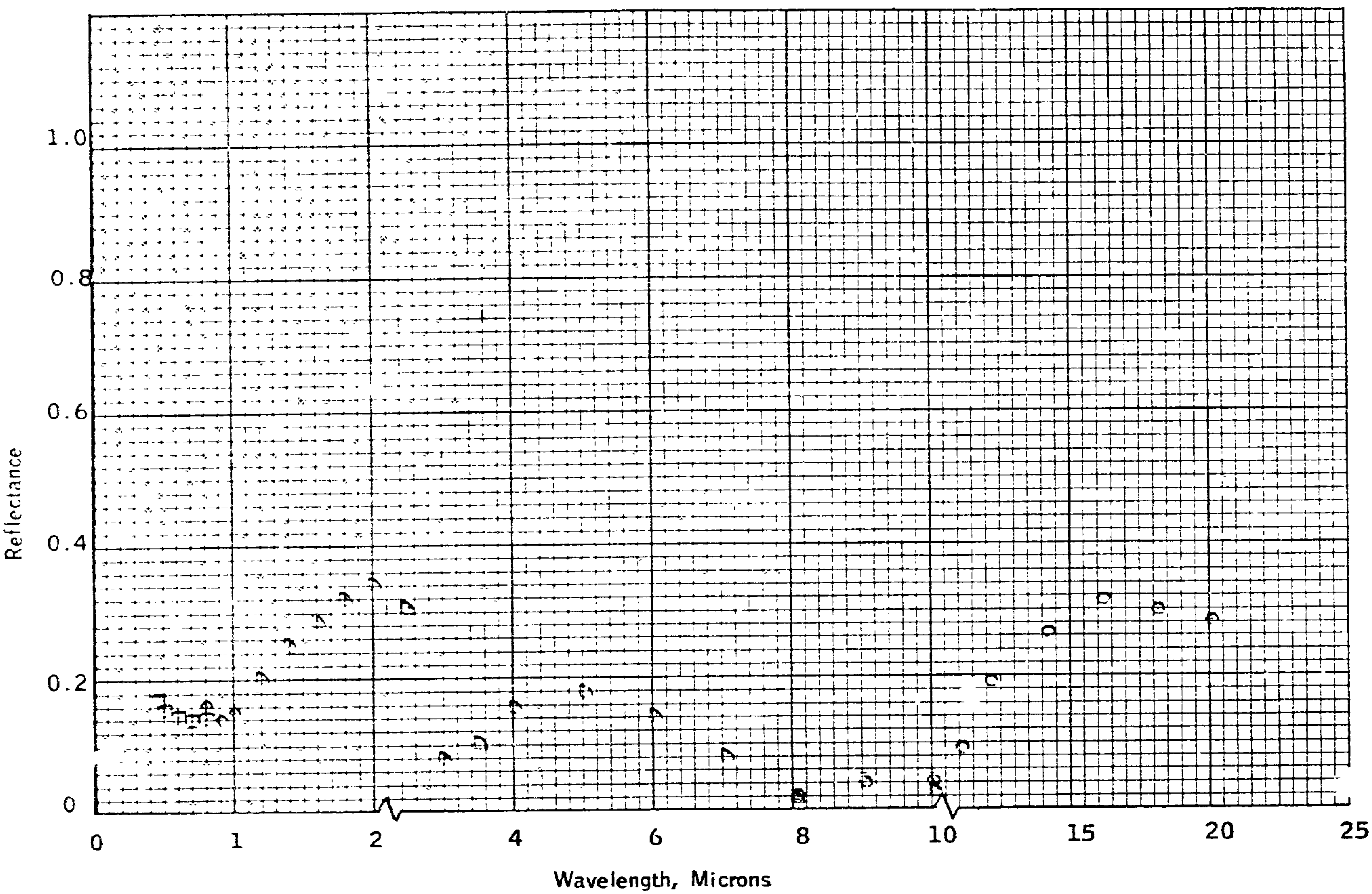


Fig. 63 Normal Spectral Reflectance of Specimen No 85 Temperature RT

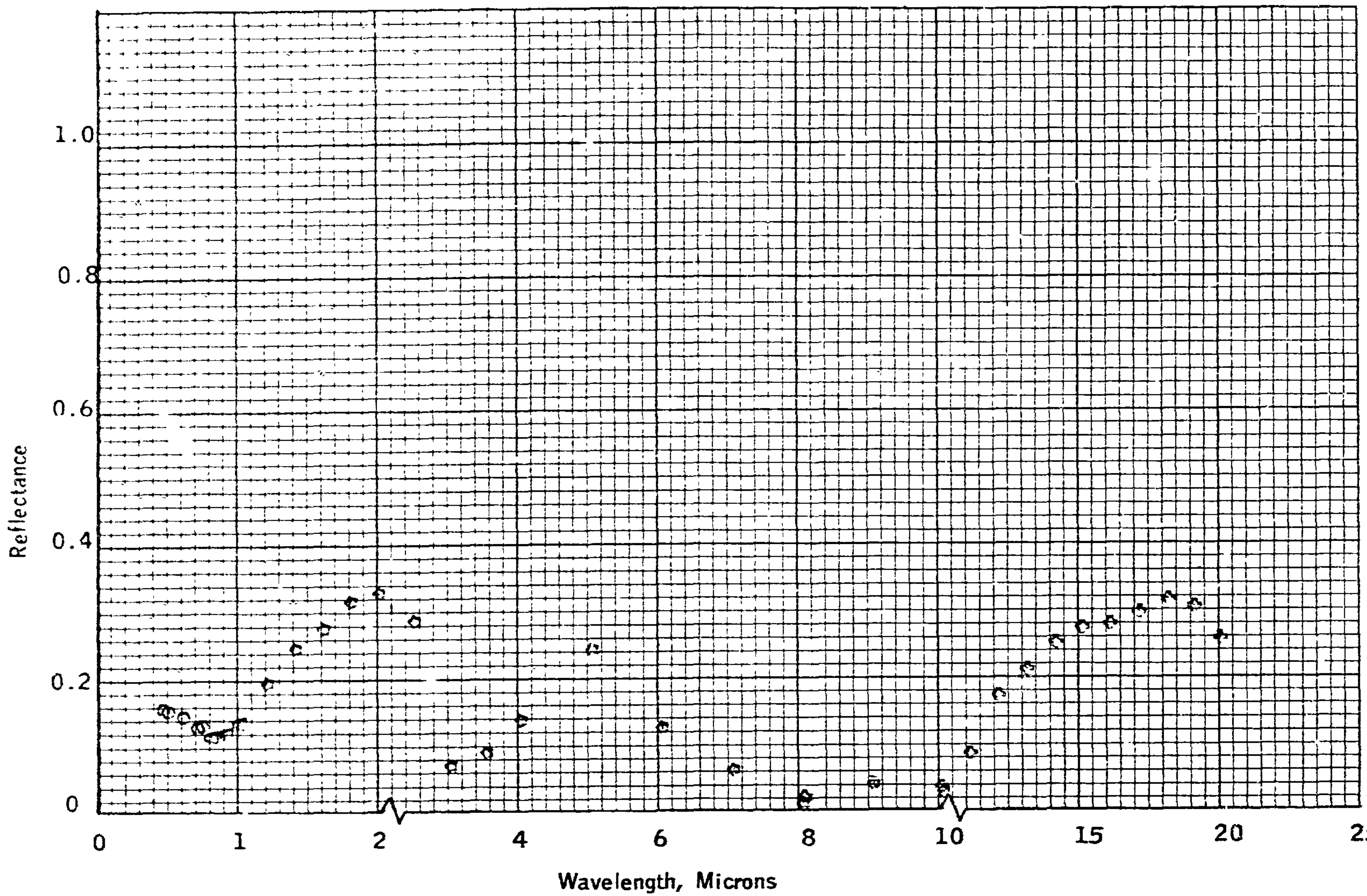


Fig. 64 Normal Spectral Reflectance of Specimen No 86 Temperature RT

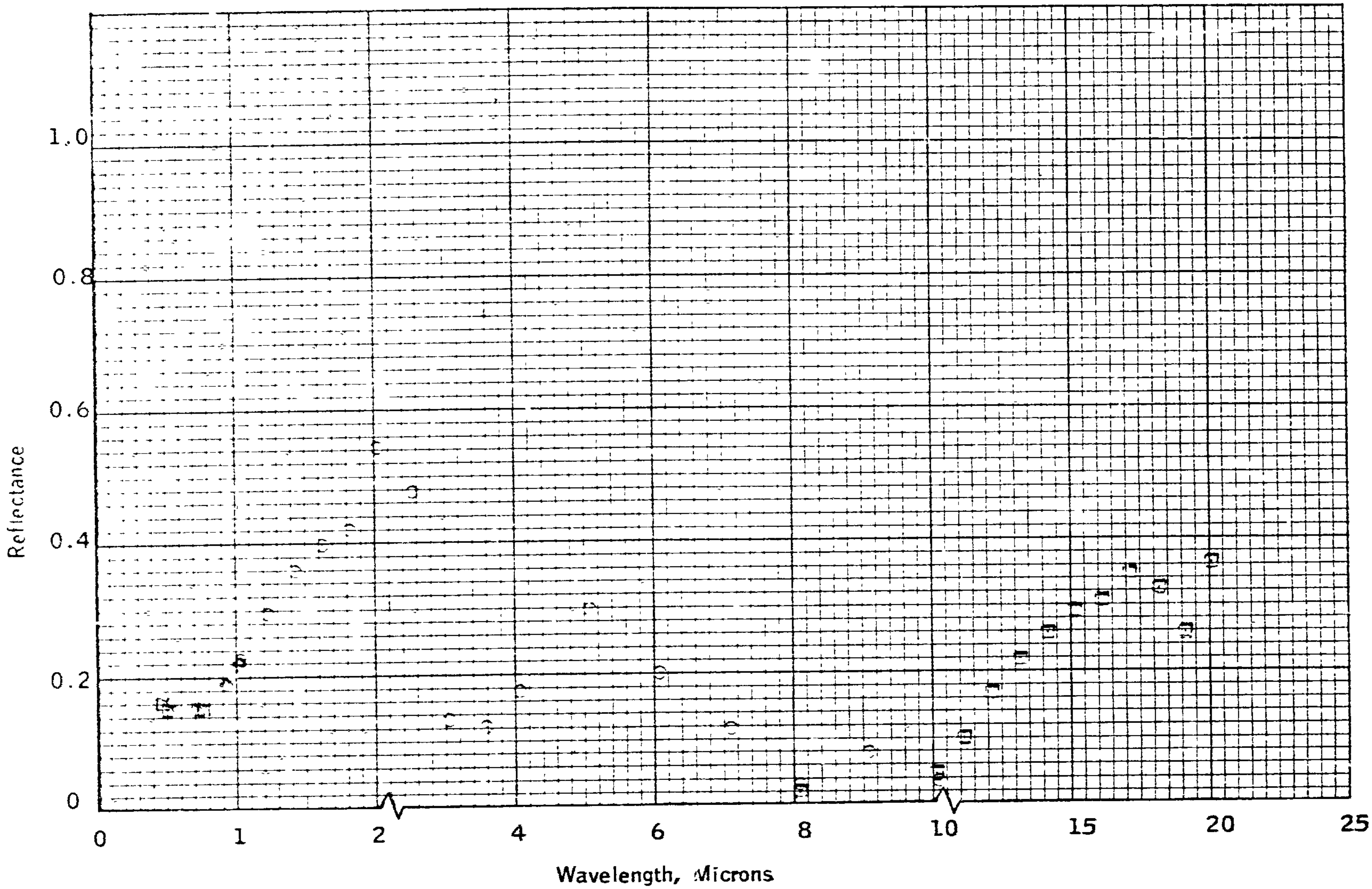


Fig. 65 Normal Spectral Reflectance of Specimen No 87 Temperature RT

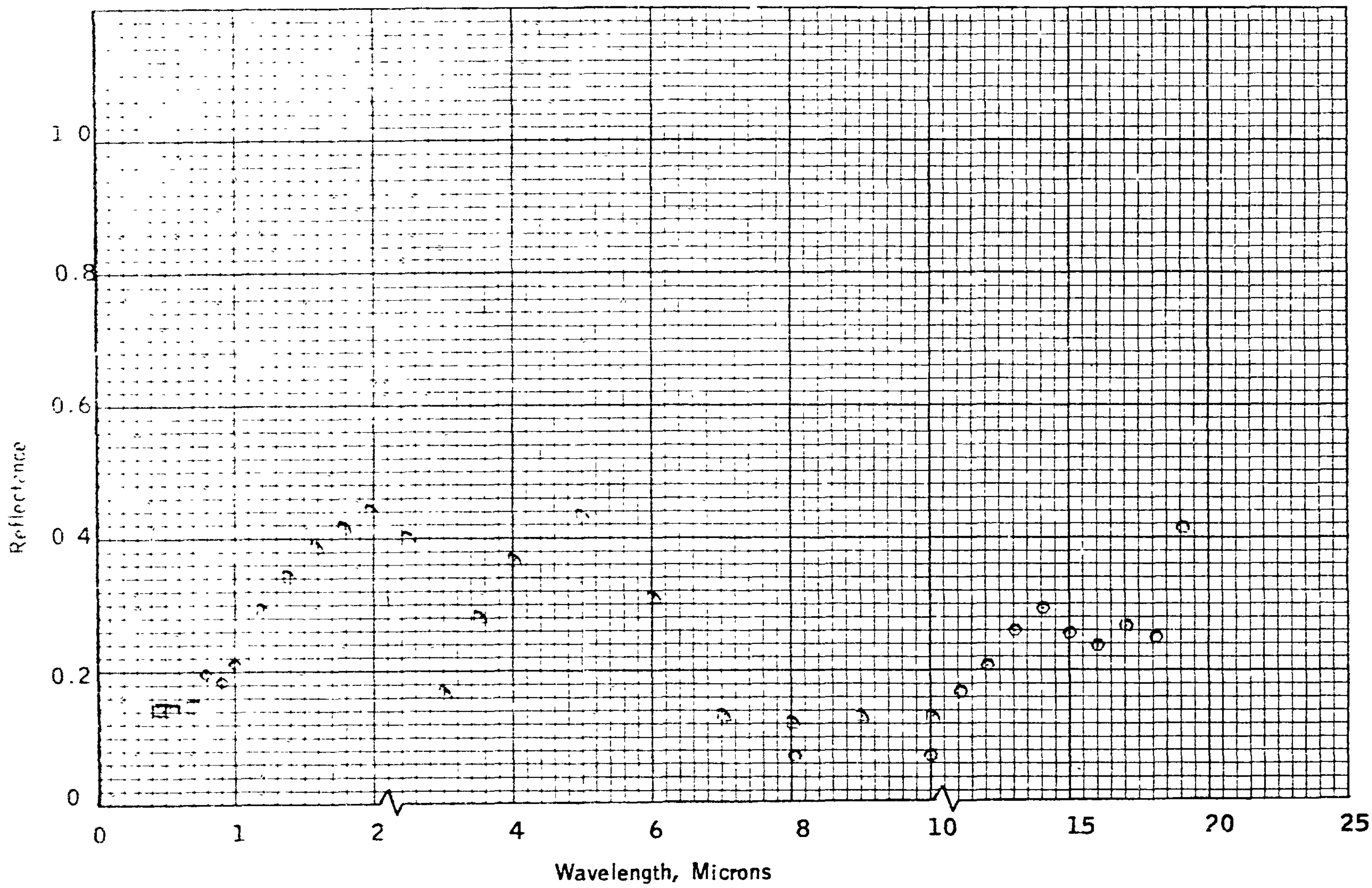


Fig. 66 Normal Spectral Reflectance of Specimen No 87 Temperature 300F

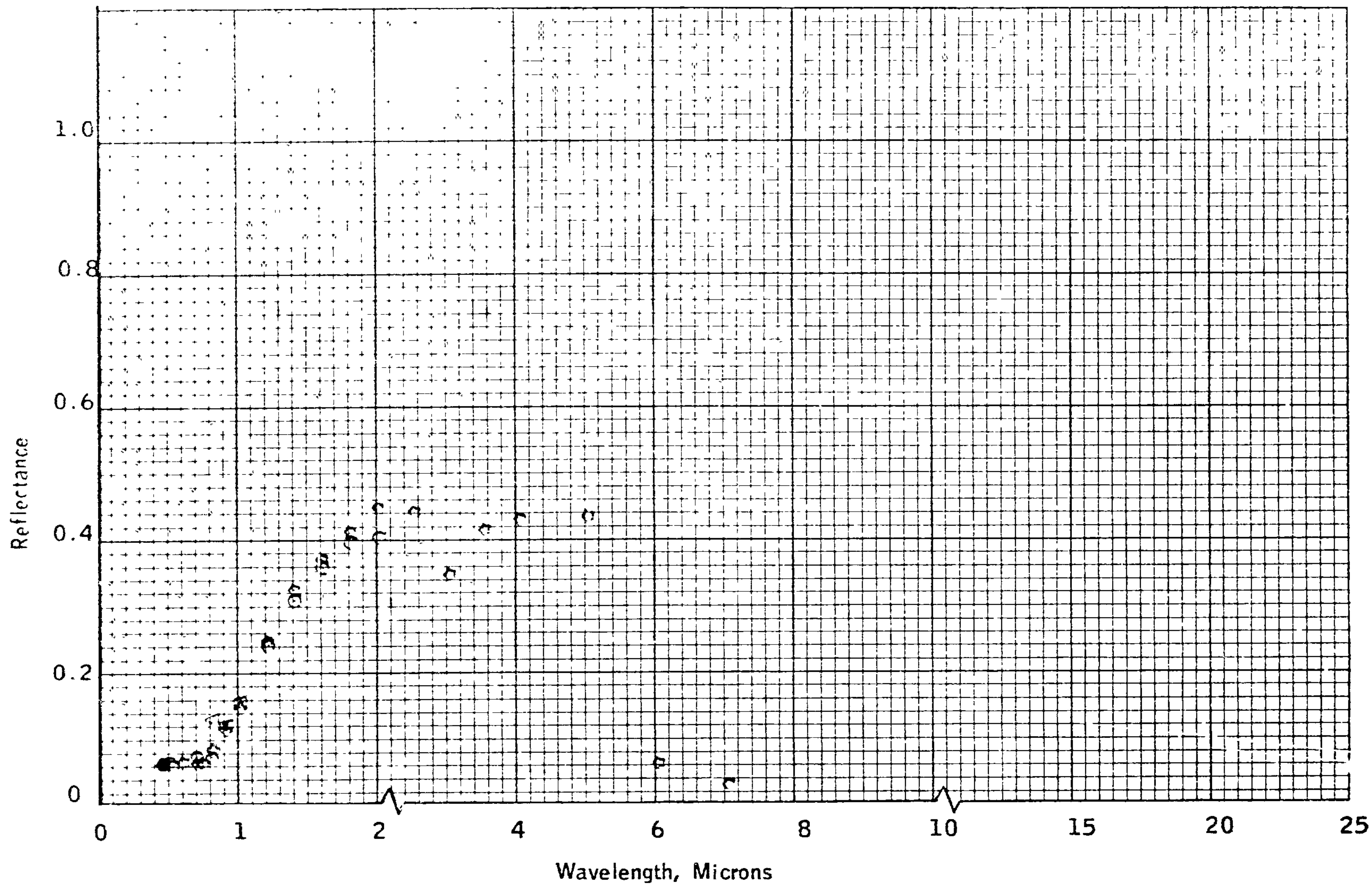


Fig. 67 Normal Spectral Reflectance of Specimen No 87 Temperature 600 F

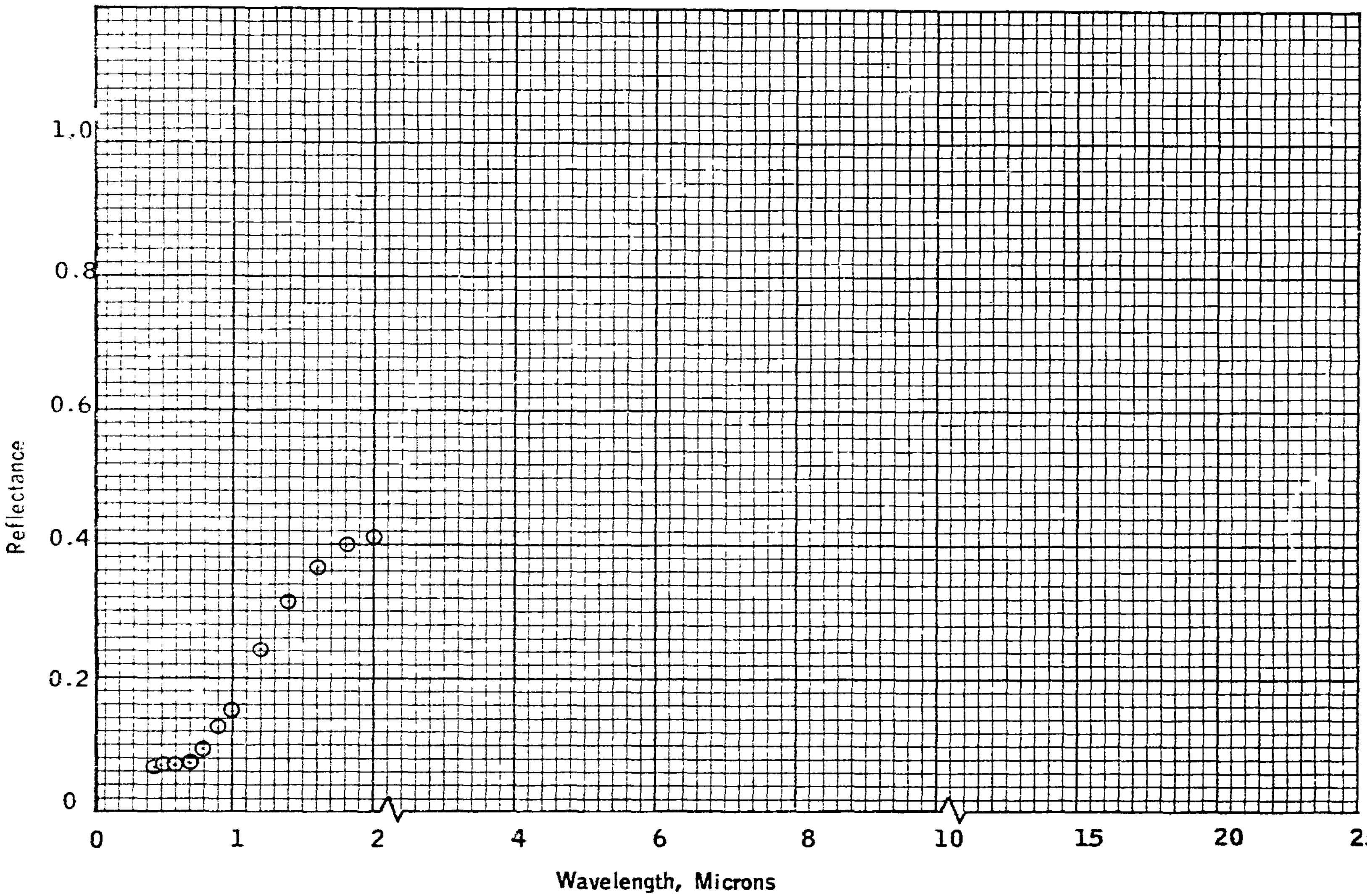


Fig. 68 Normal Spectral Reflectance of Specimen No 87 Temperature 825 F

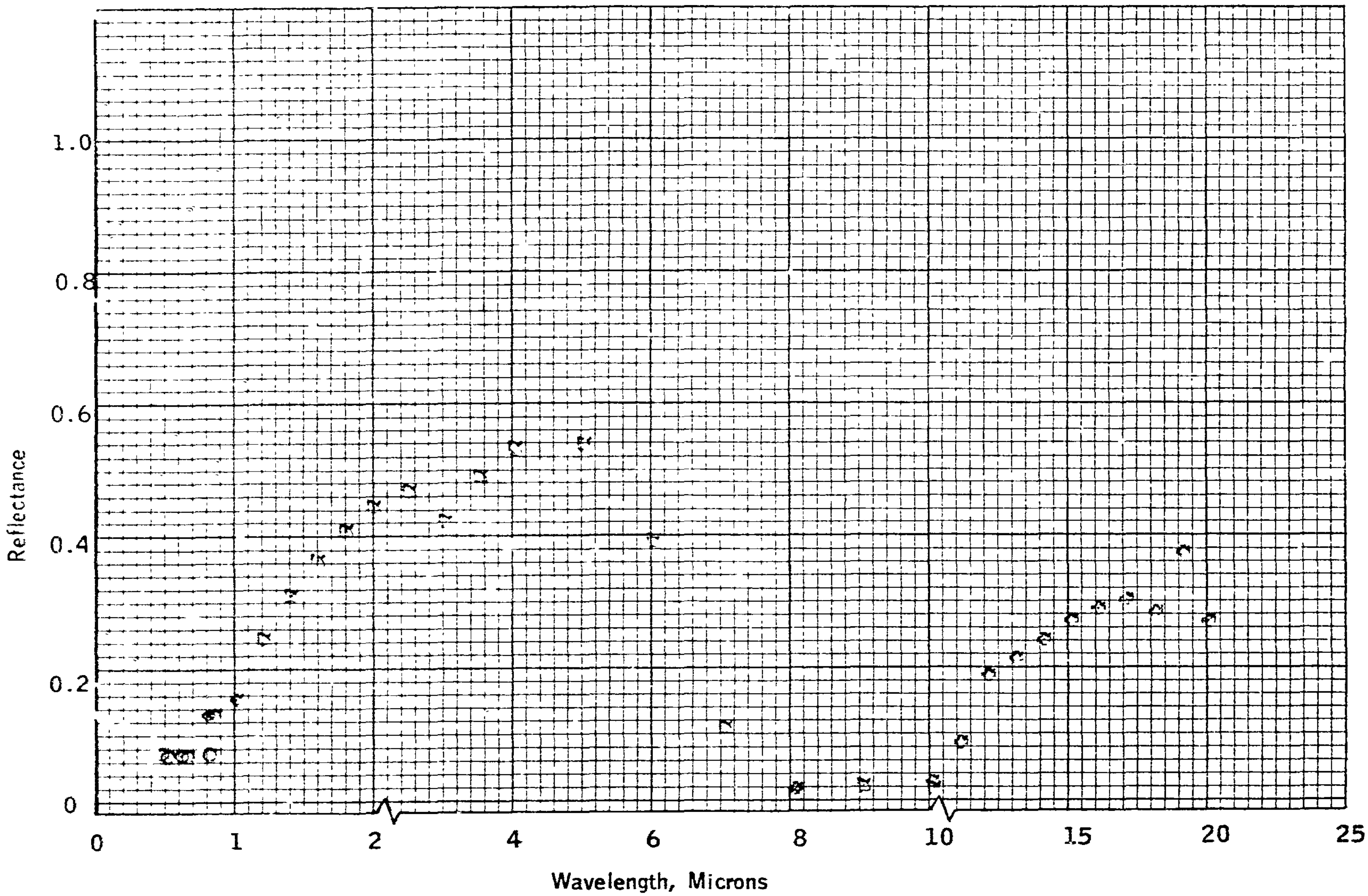


Fig. 69 Normal Spectral Reflectance of Specimen No 87 Temperature RT_f

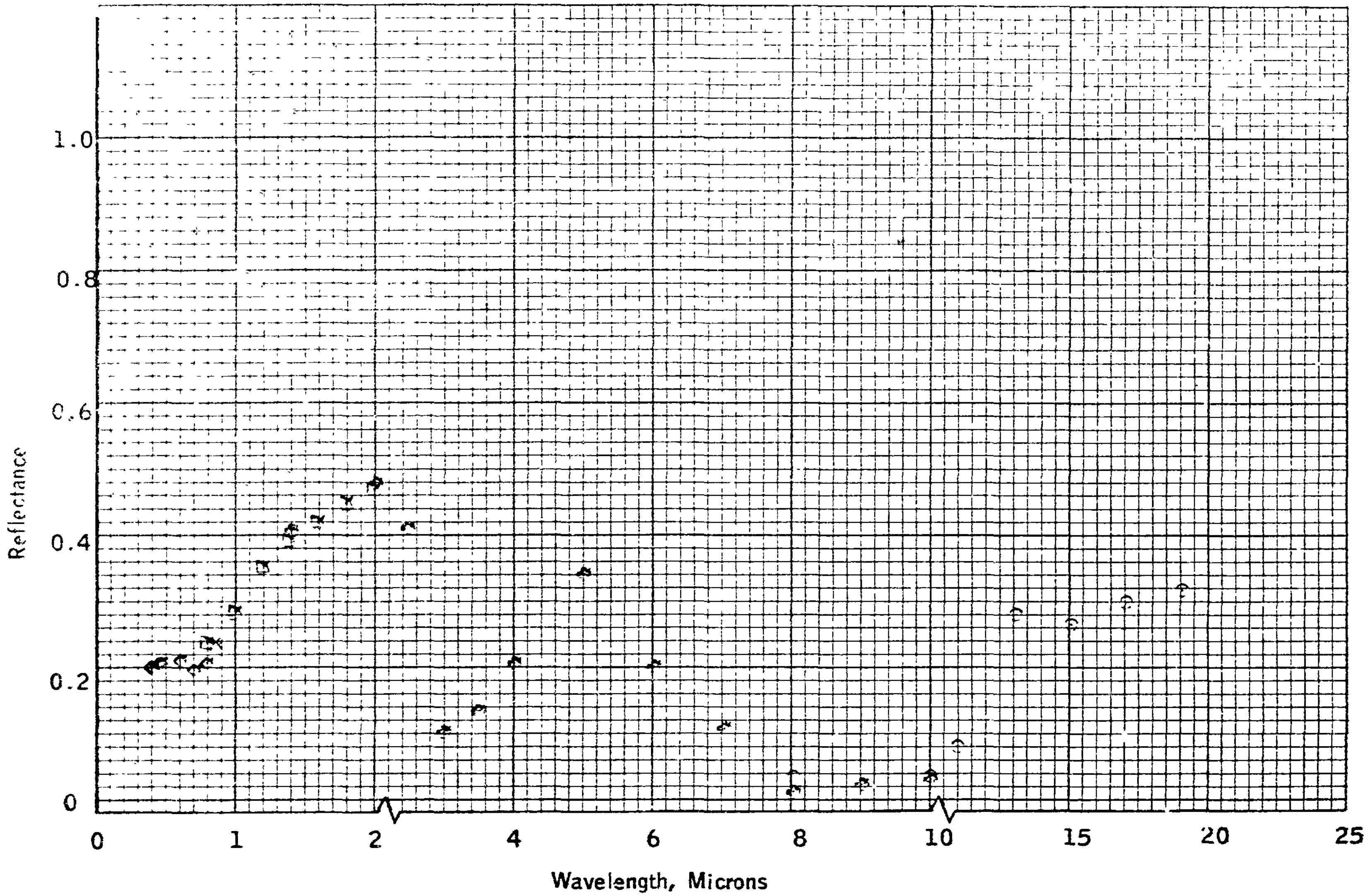


Fig. 70 Normal Spectral Reflectance of Specimen No 88 Temperature RT, H T-800F

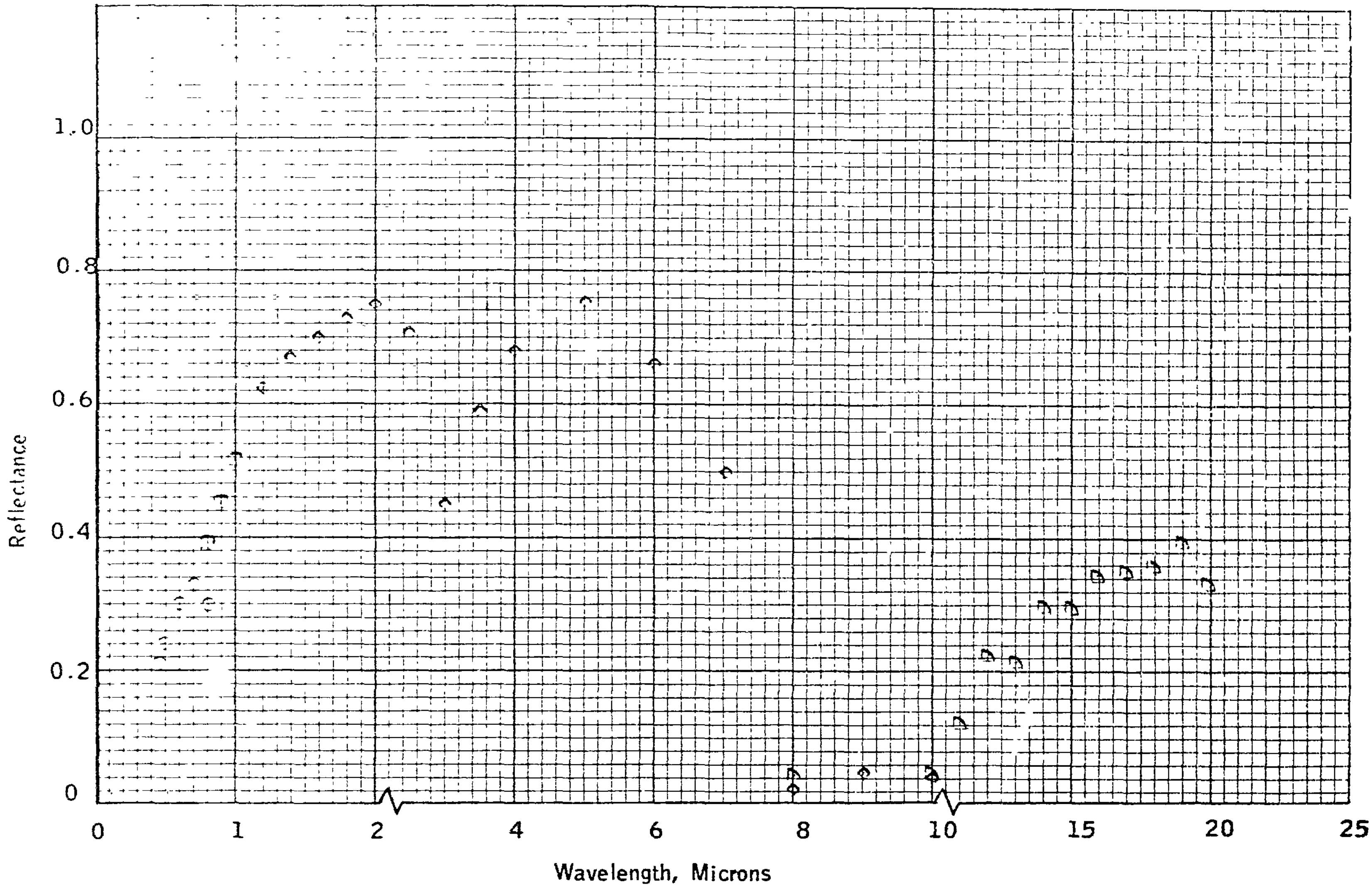


Fig. 71 Normal Spectral Reflectance of Specimen No 89 Temperature RT

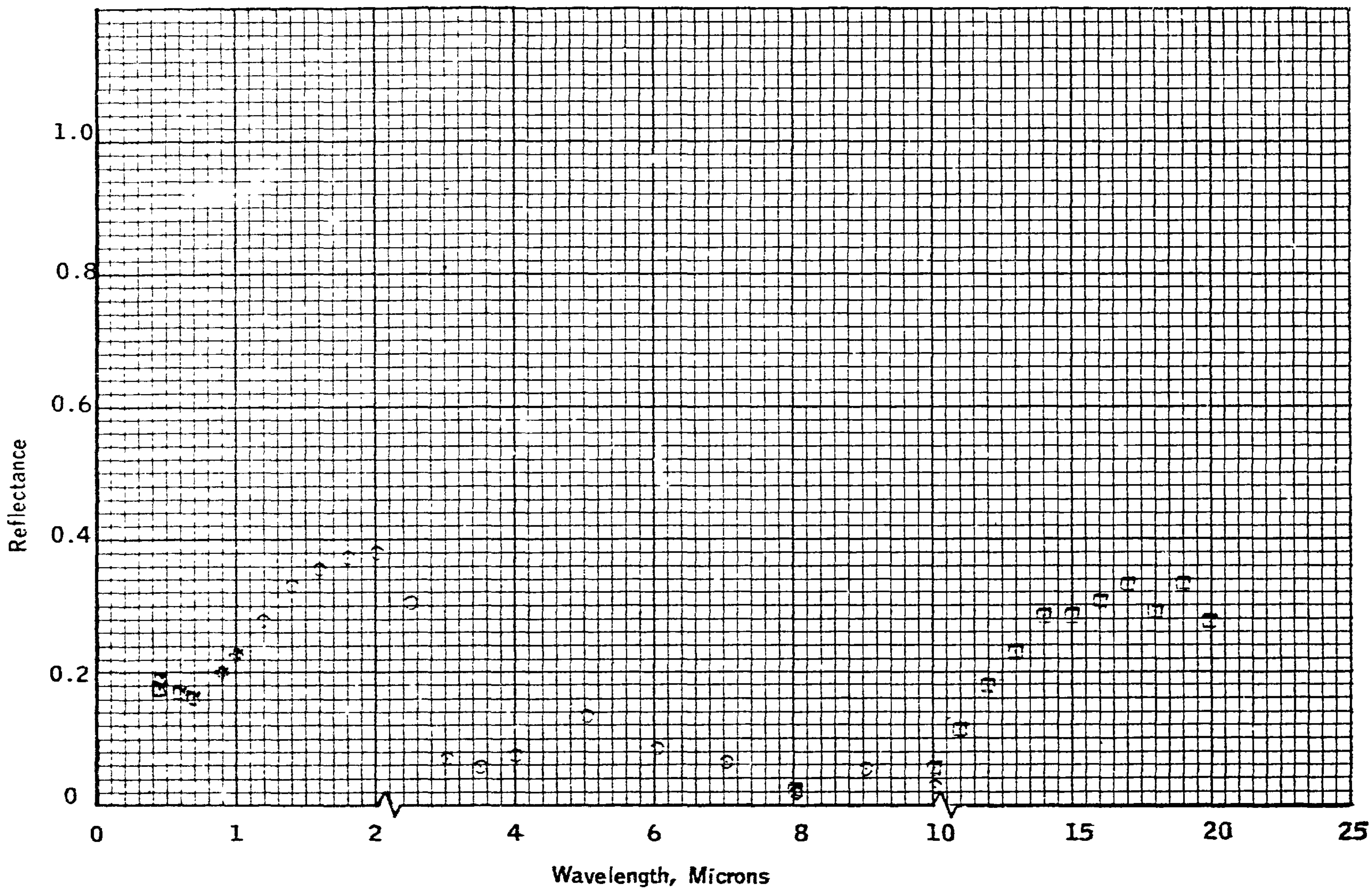


Fig. 72 Normal Spectral Reflectance of Specimen No 129 Temperature RT

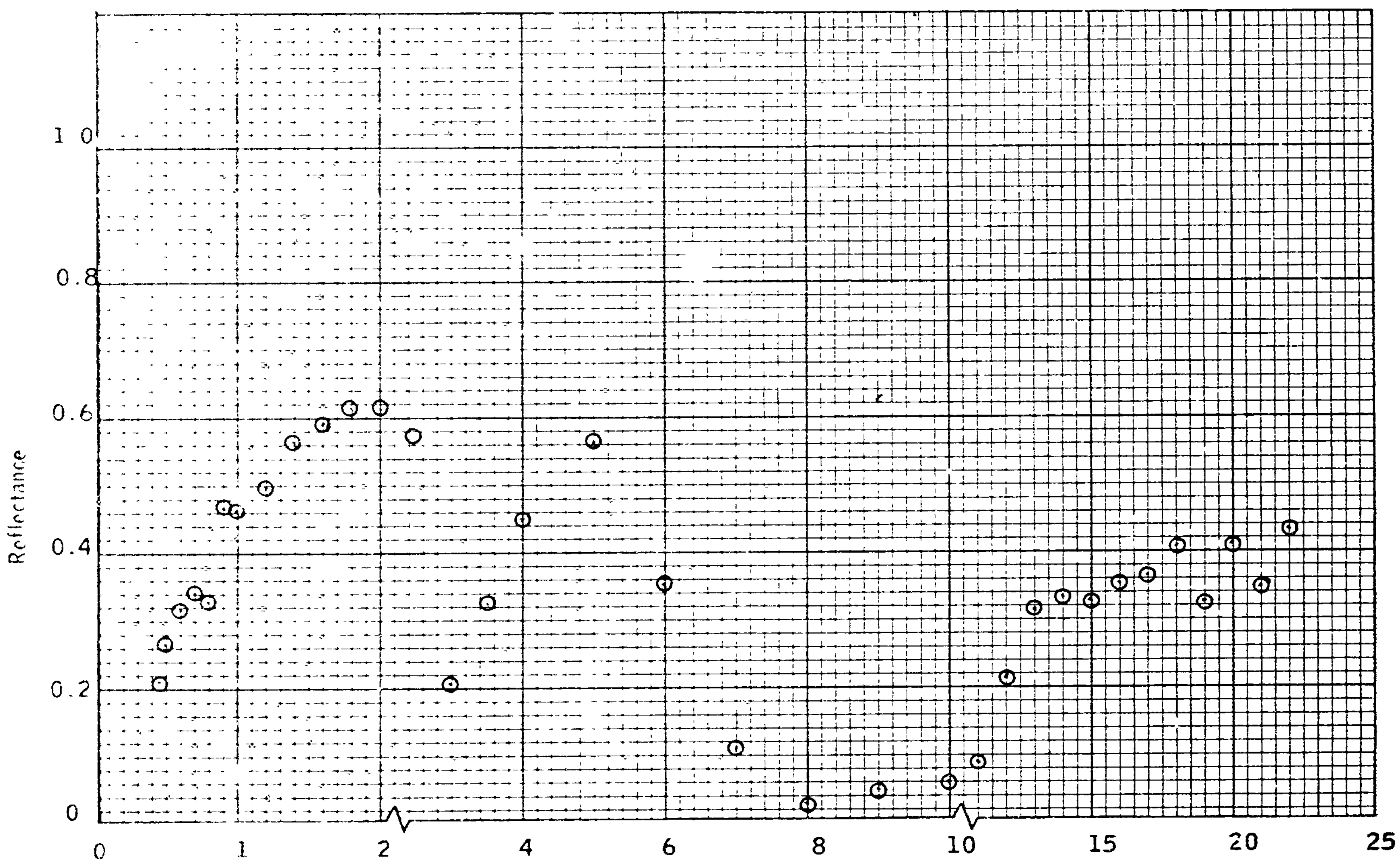


Fig. 73 Normal Spectral Reflectance of Specimen No 13 Temperature RT

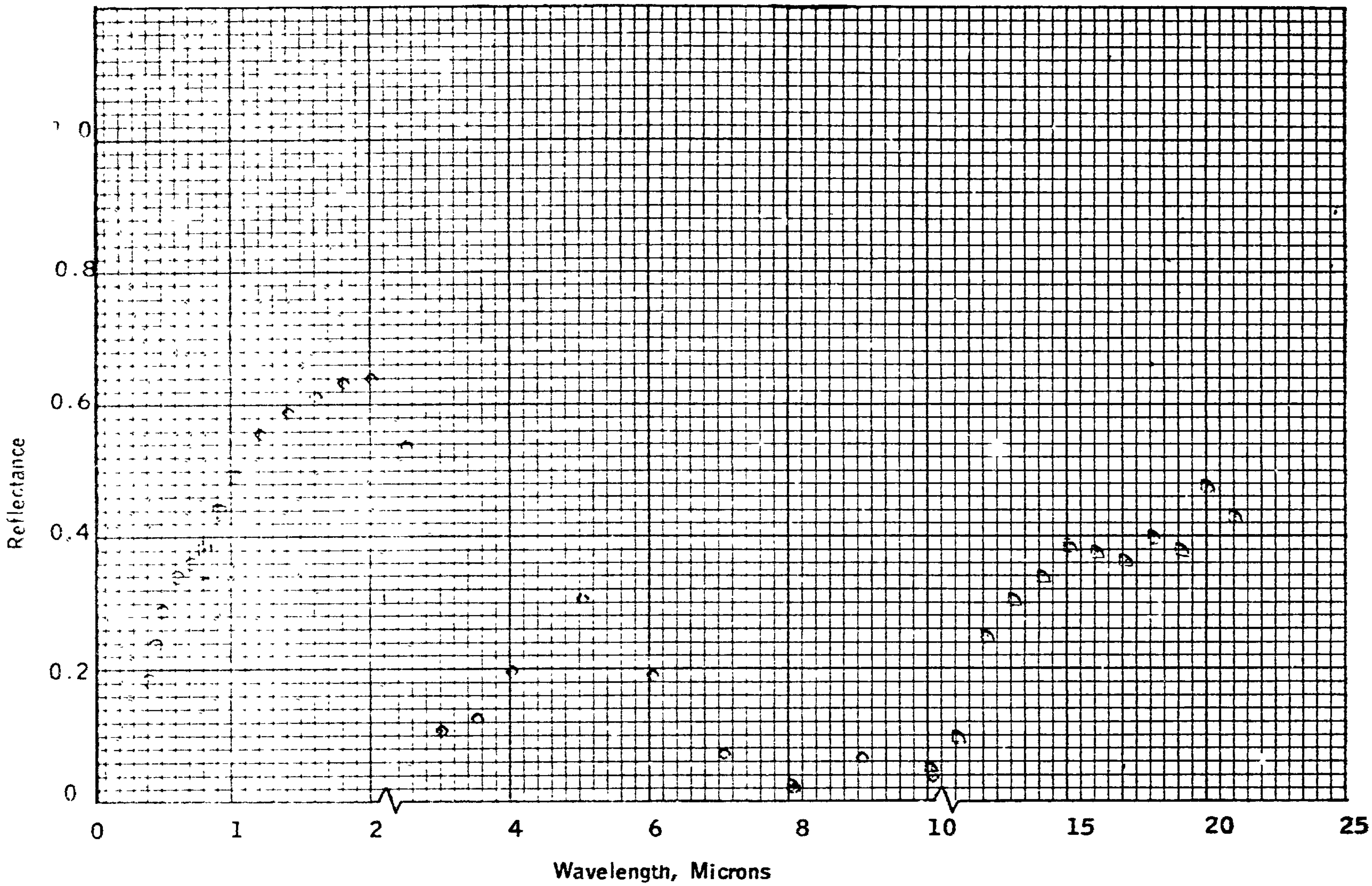


Fig. 74 Normal Spectral Reflectance of Specimen Nc 15 Temperature RT

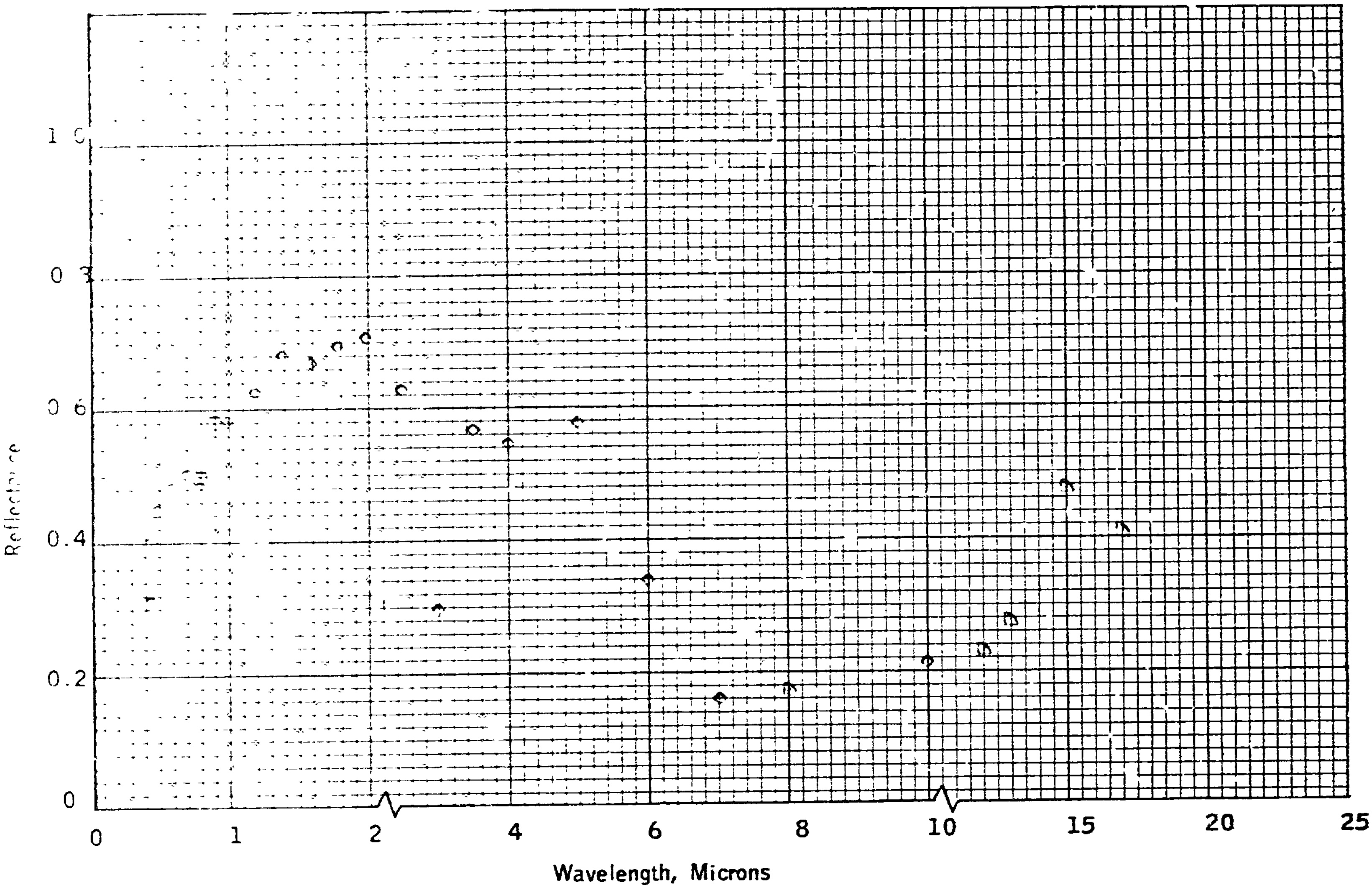


Fig. 75 Normal Spectral Reflectance of Specimen No 15 Temperature 600F

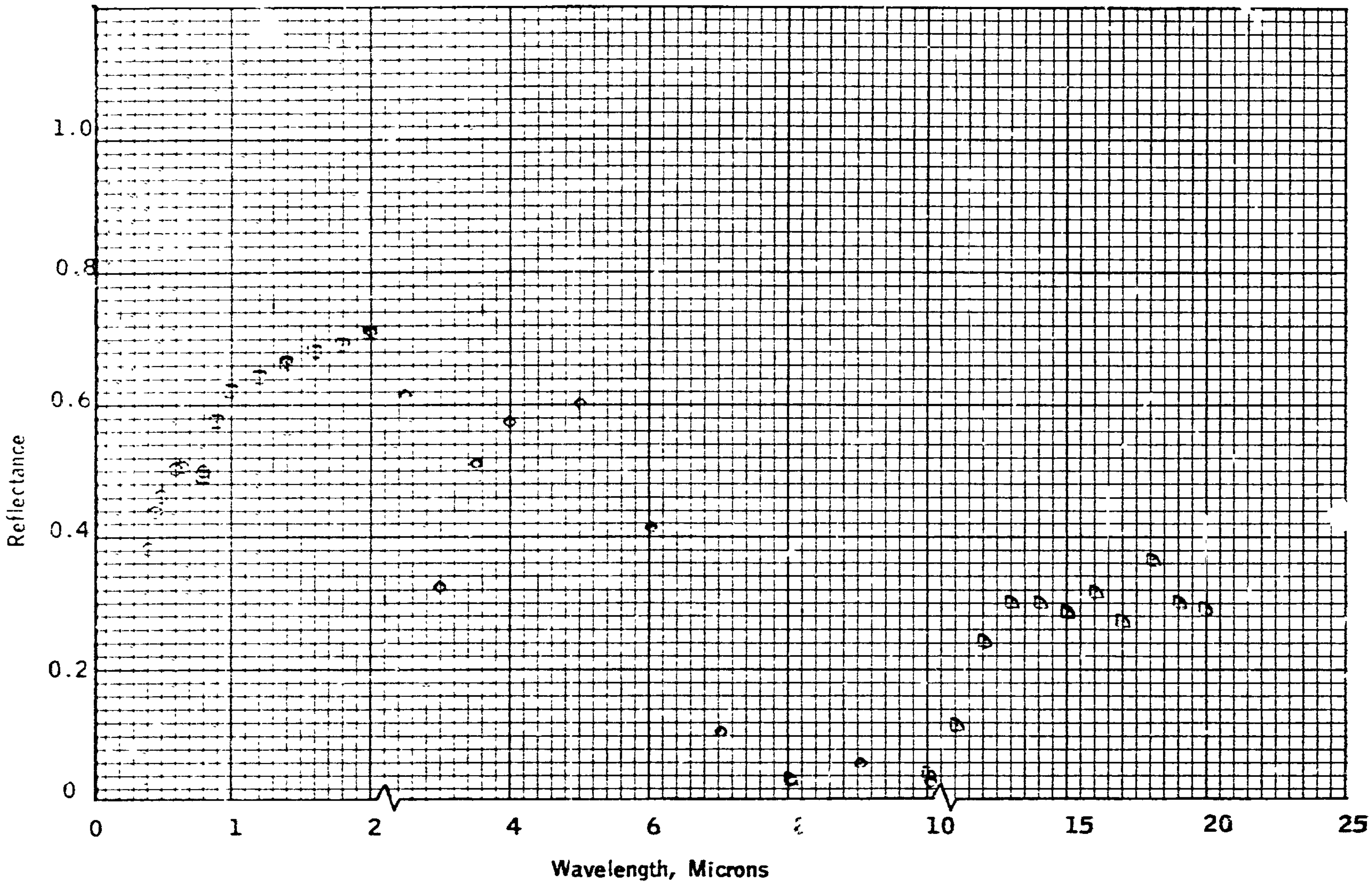


Fig. 76 Normal Spectral Reflectance of Specimen No 15 Temperature RT

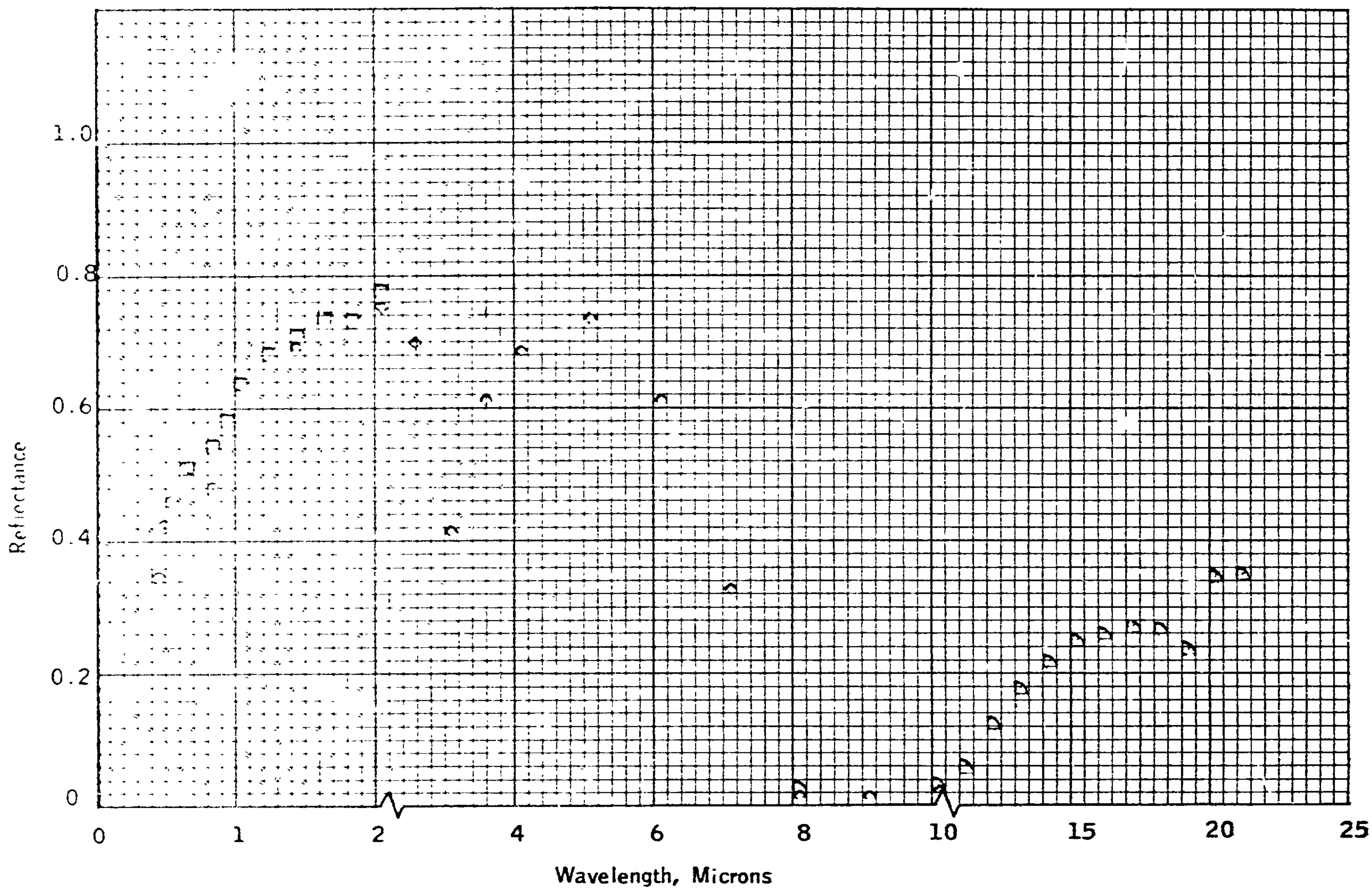


Fig. 77 Normal Spectral Reflectance of Specimen No 20 Temperature RT

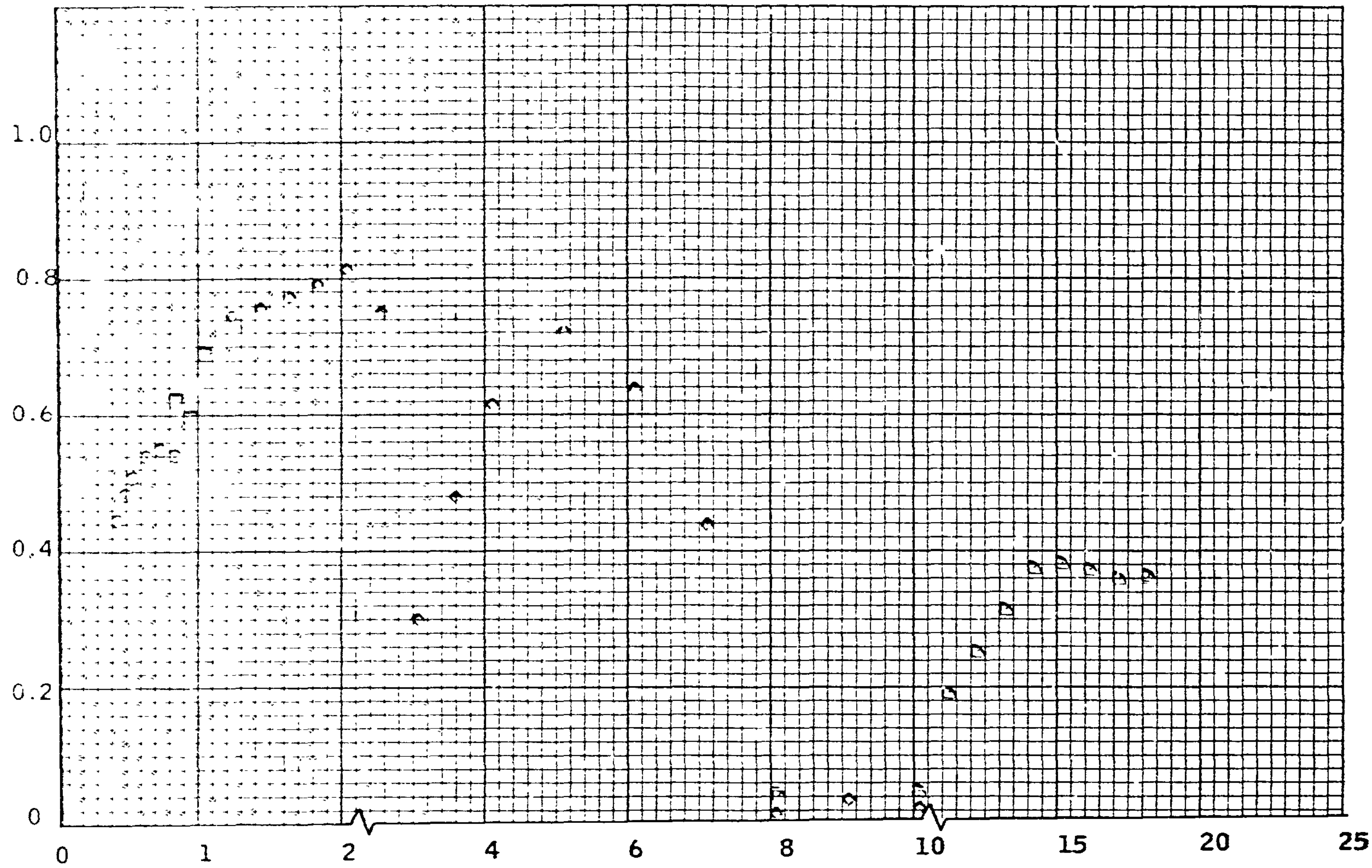


Fig. 78 Normal Spectral Reflectance of Specimen No 23 Temperature RT

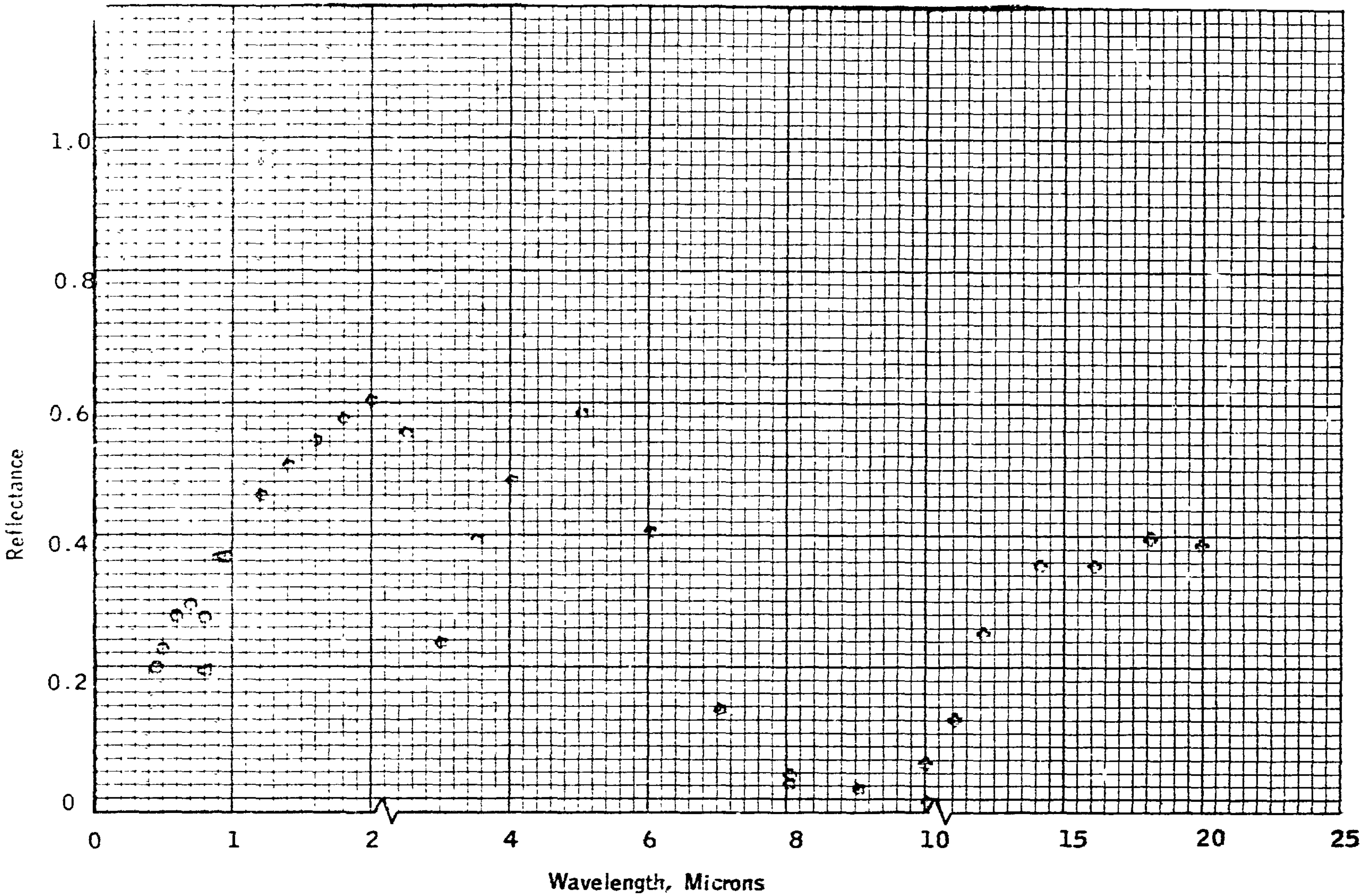


Fig. 79 Normal Spectral Reflectance of Specimen No 82 Temperature RT

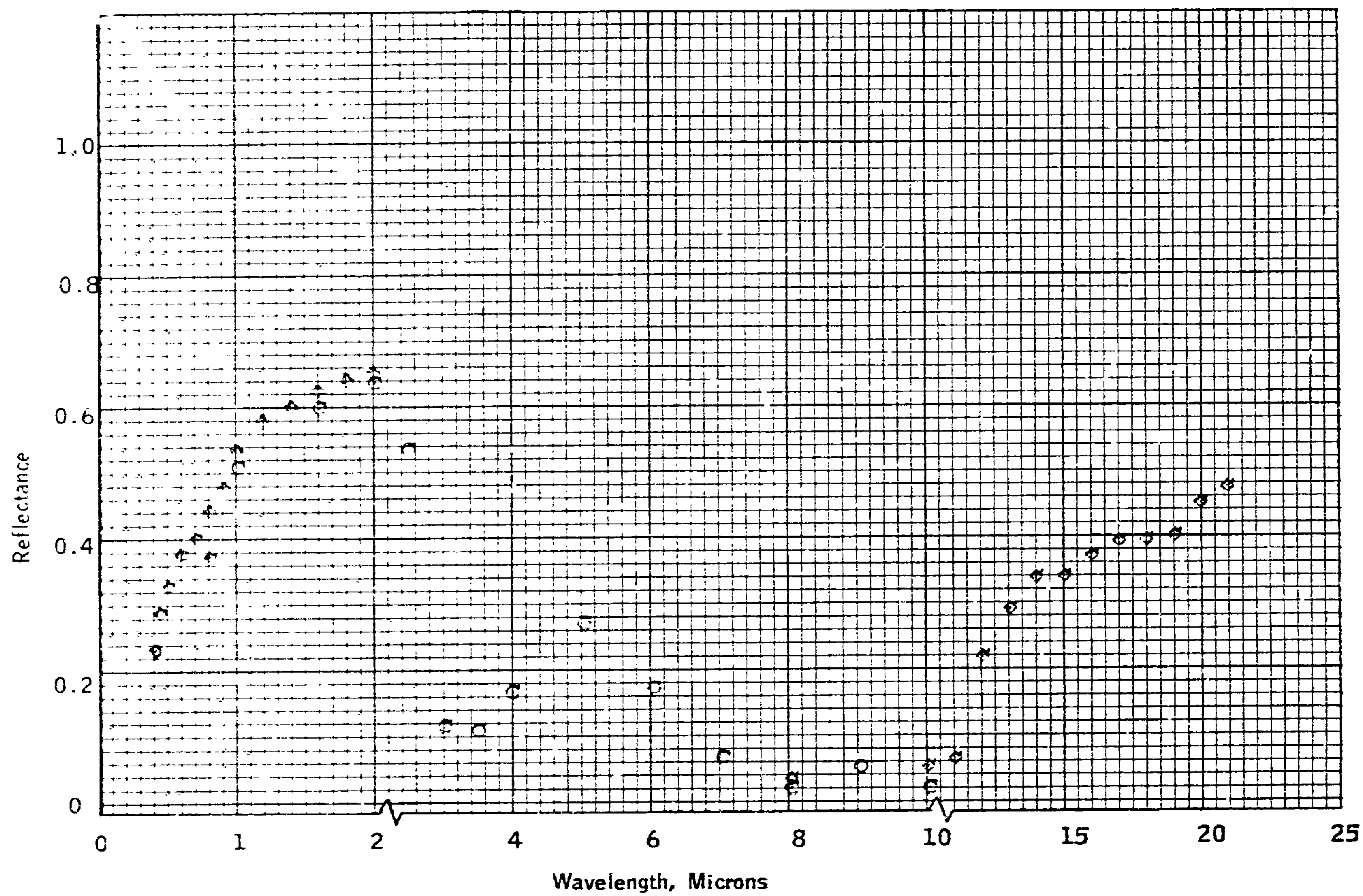


Fig. 80 Normal Spectral Reflectance of Specimen No 500 Temperature RT

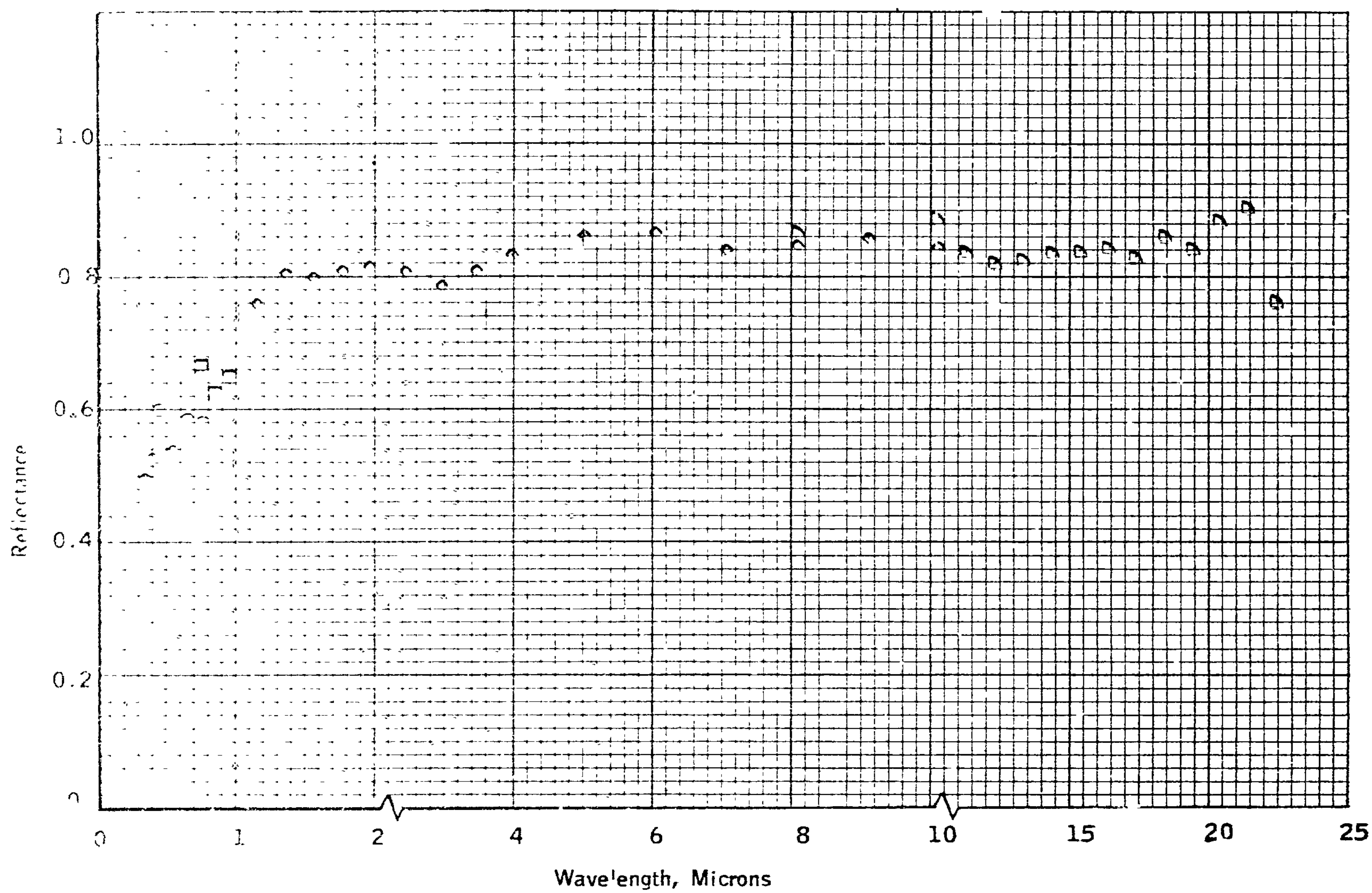


Fig. 81 Normal Spectral Reflectance of Specimen No 52 Temperature RT

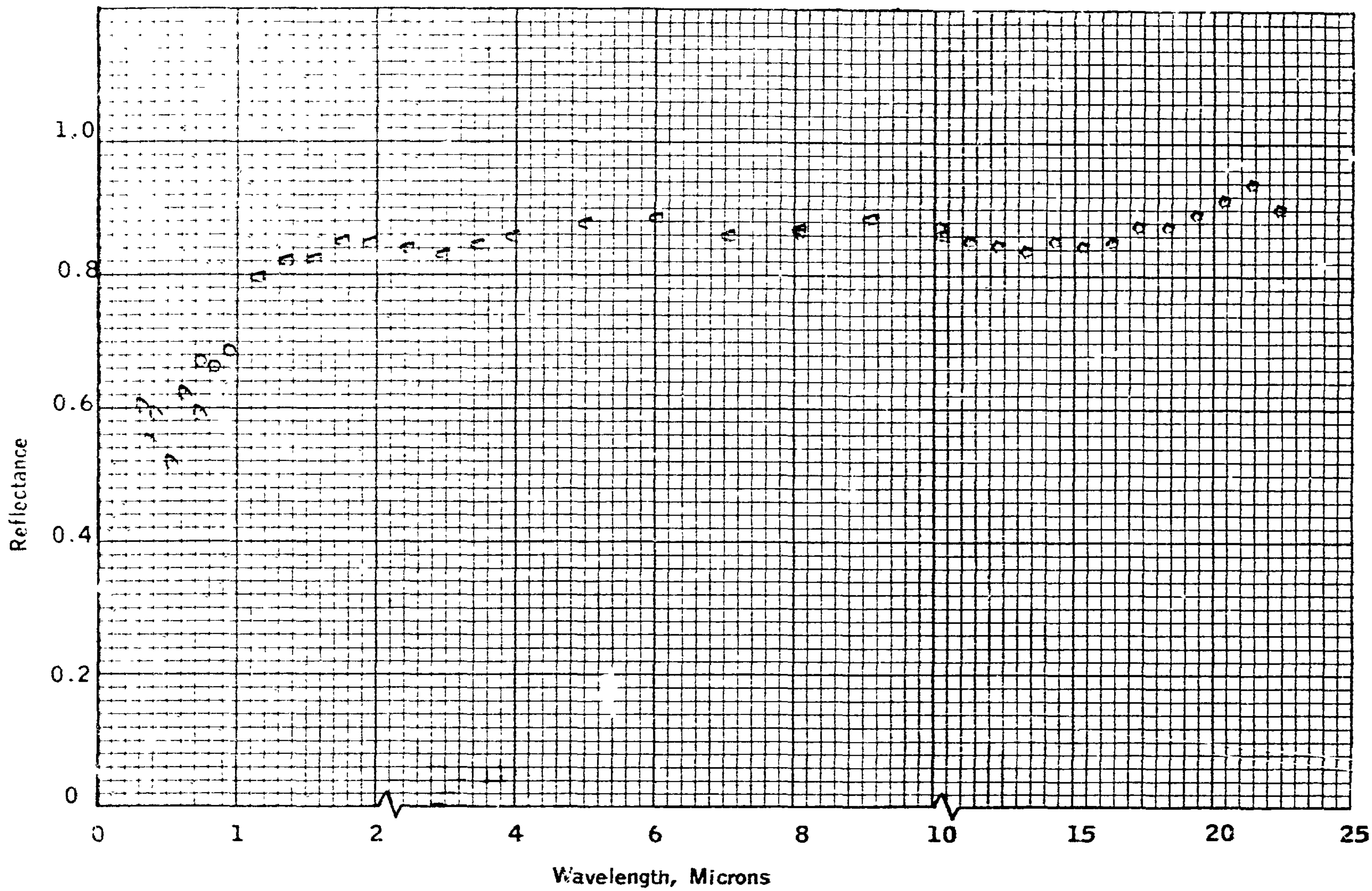


Fig. 82 Normal Spectral Reflectance of Specimen No 52 Temperature 300 F

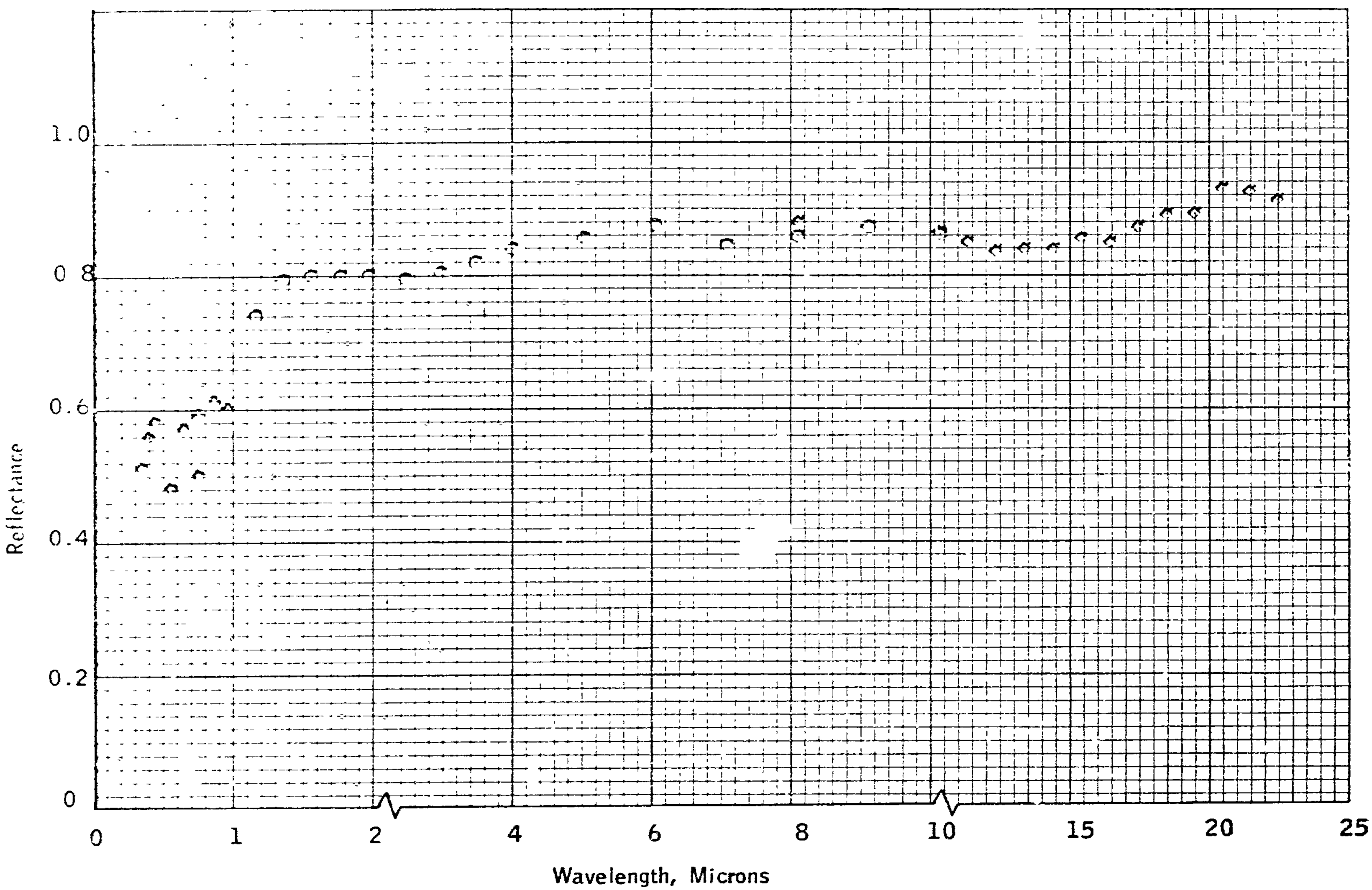


Fig. 83 Normal Spectral Reflectance of Specimen No 52 Temperature 600F

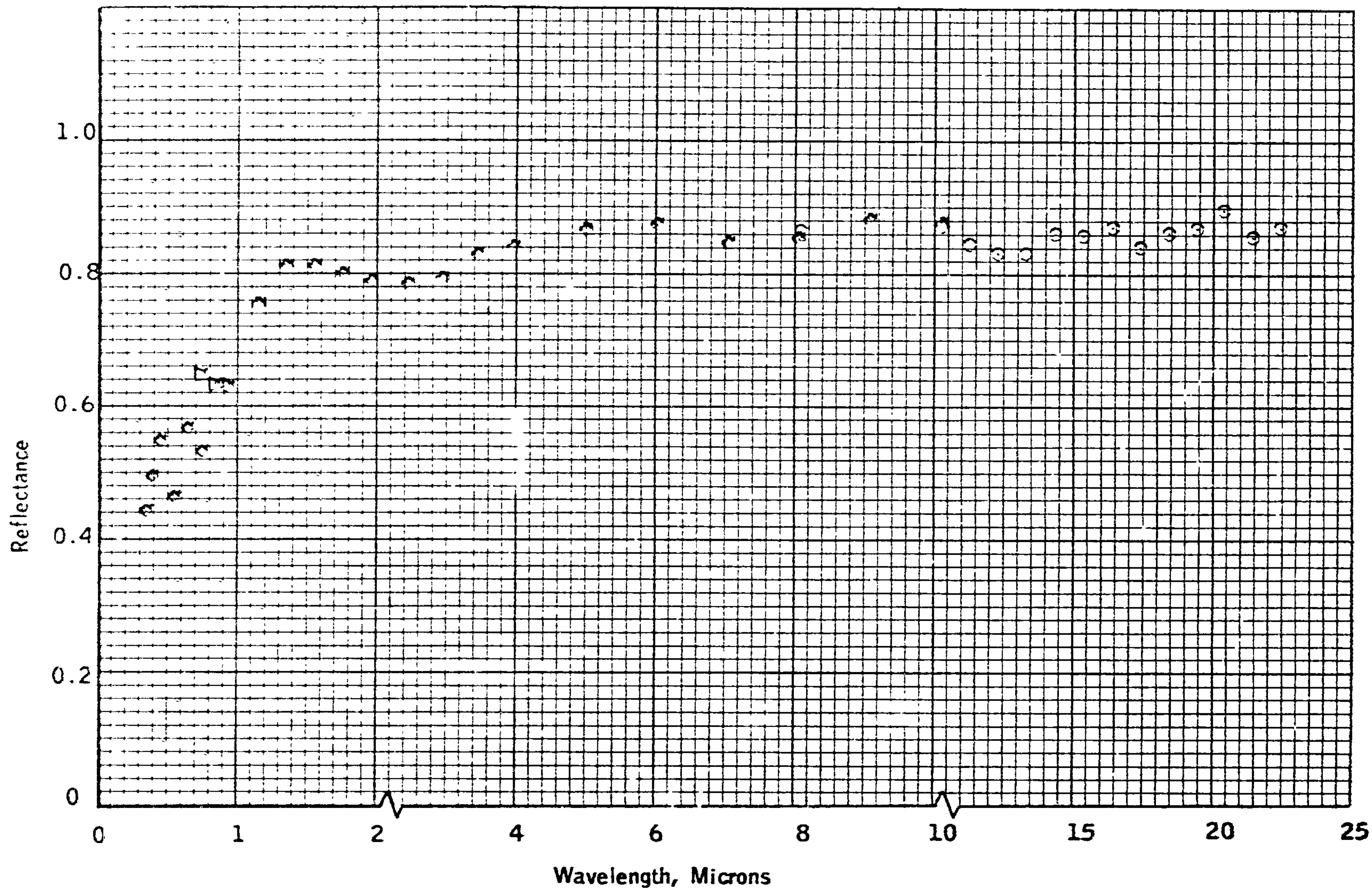


Fig. 84 Normal Spectral Reflectance of Specimen No 52 Temperature 825 F

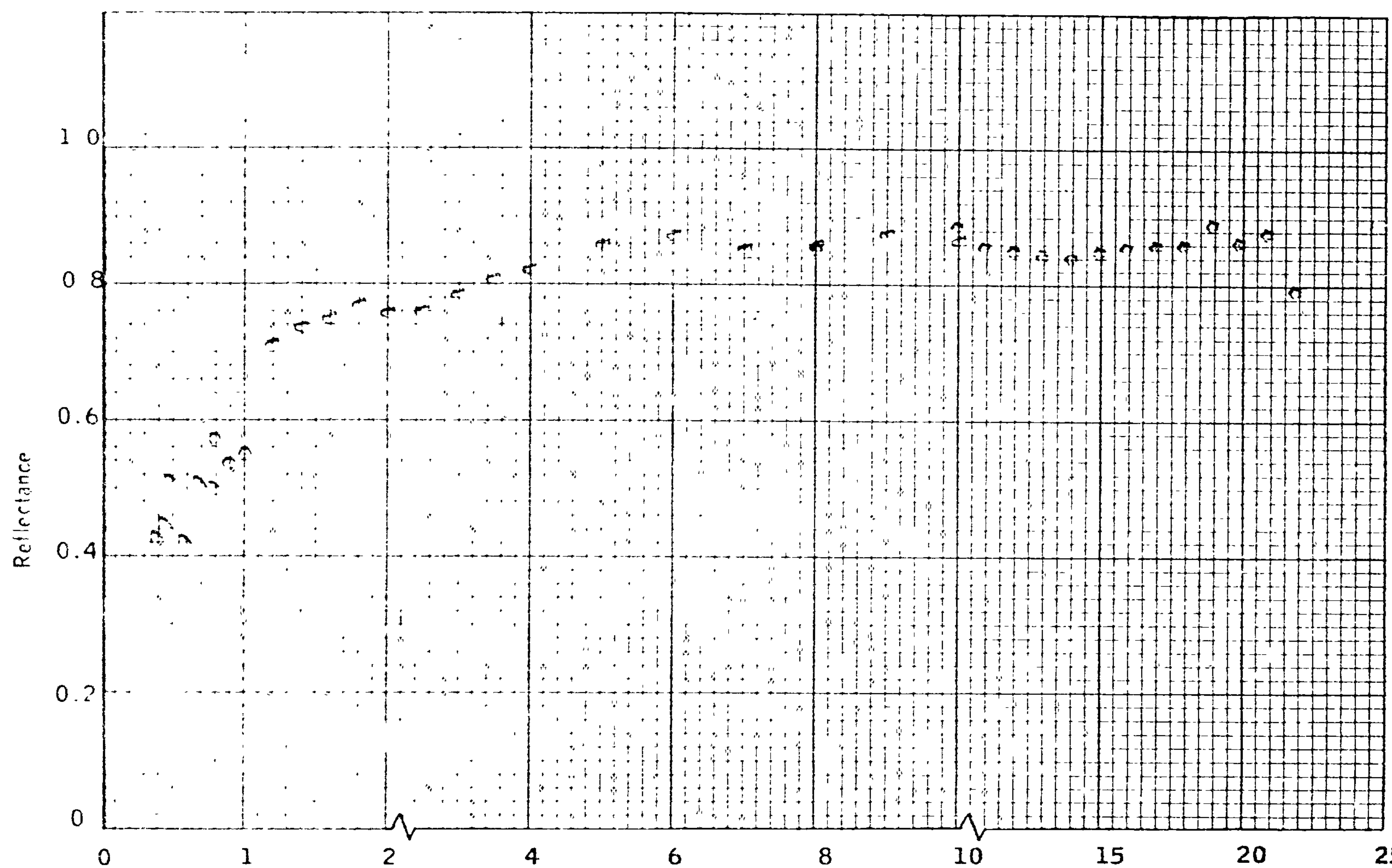


Fig. 85 Normal Spectral Reflectance of Specimen No 52 Temperature RT_f

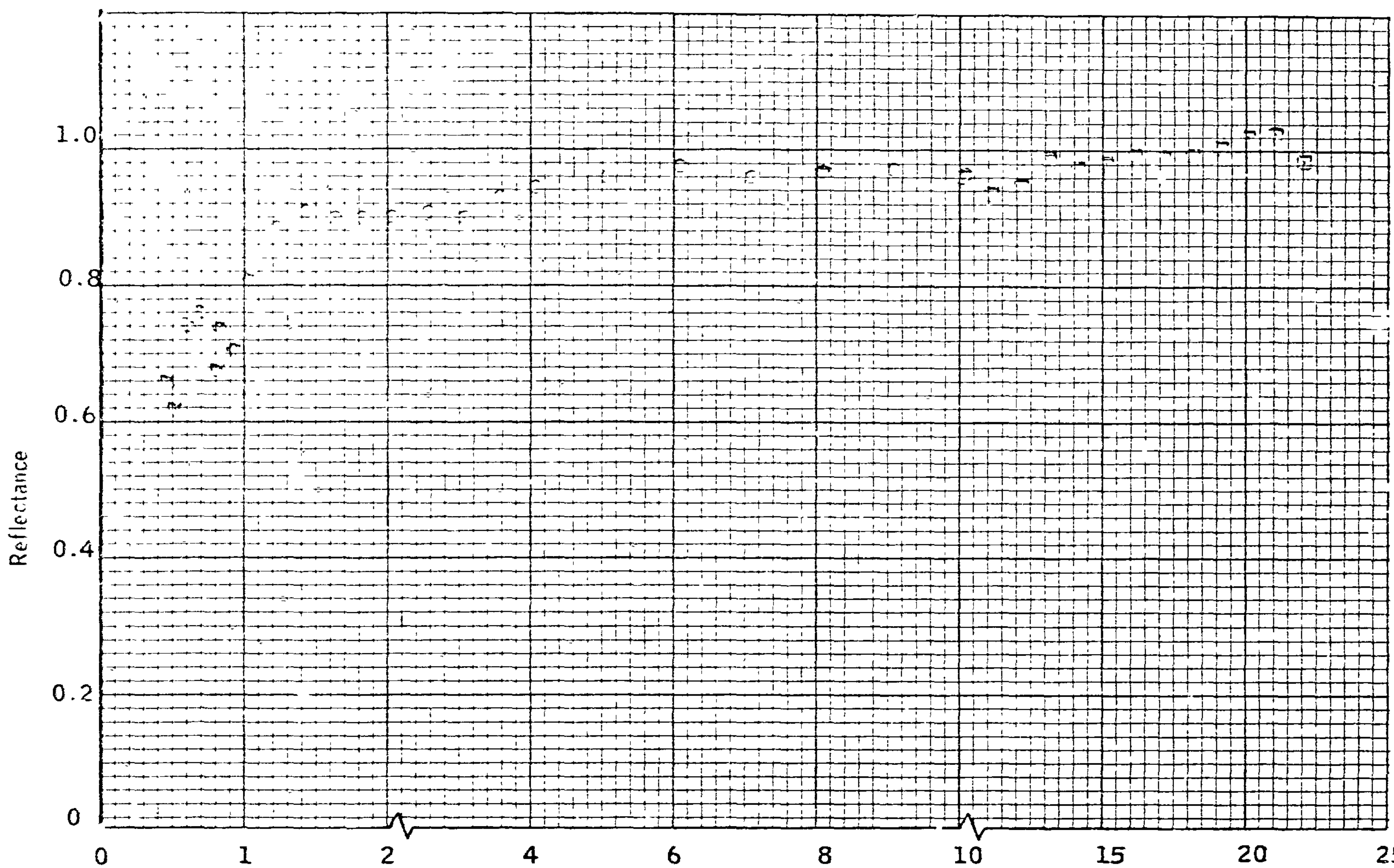


Fig. 87 Normal Spectral Reflectance of Specimen No 62 Temperature RT

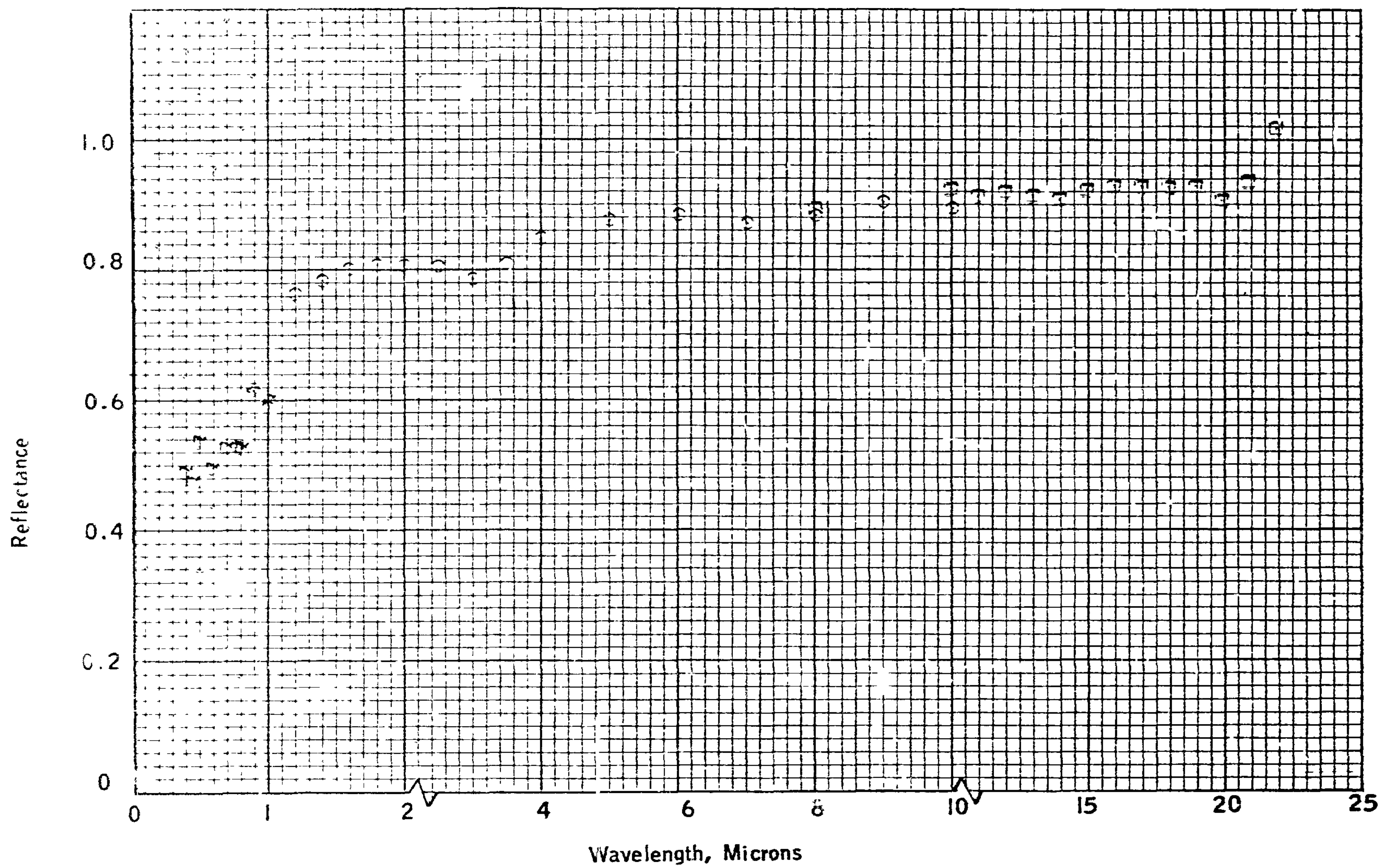


Fig. 88 Normal Spectral Reflectance of Specimen No 115 Temperature RT

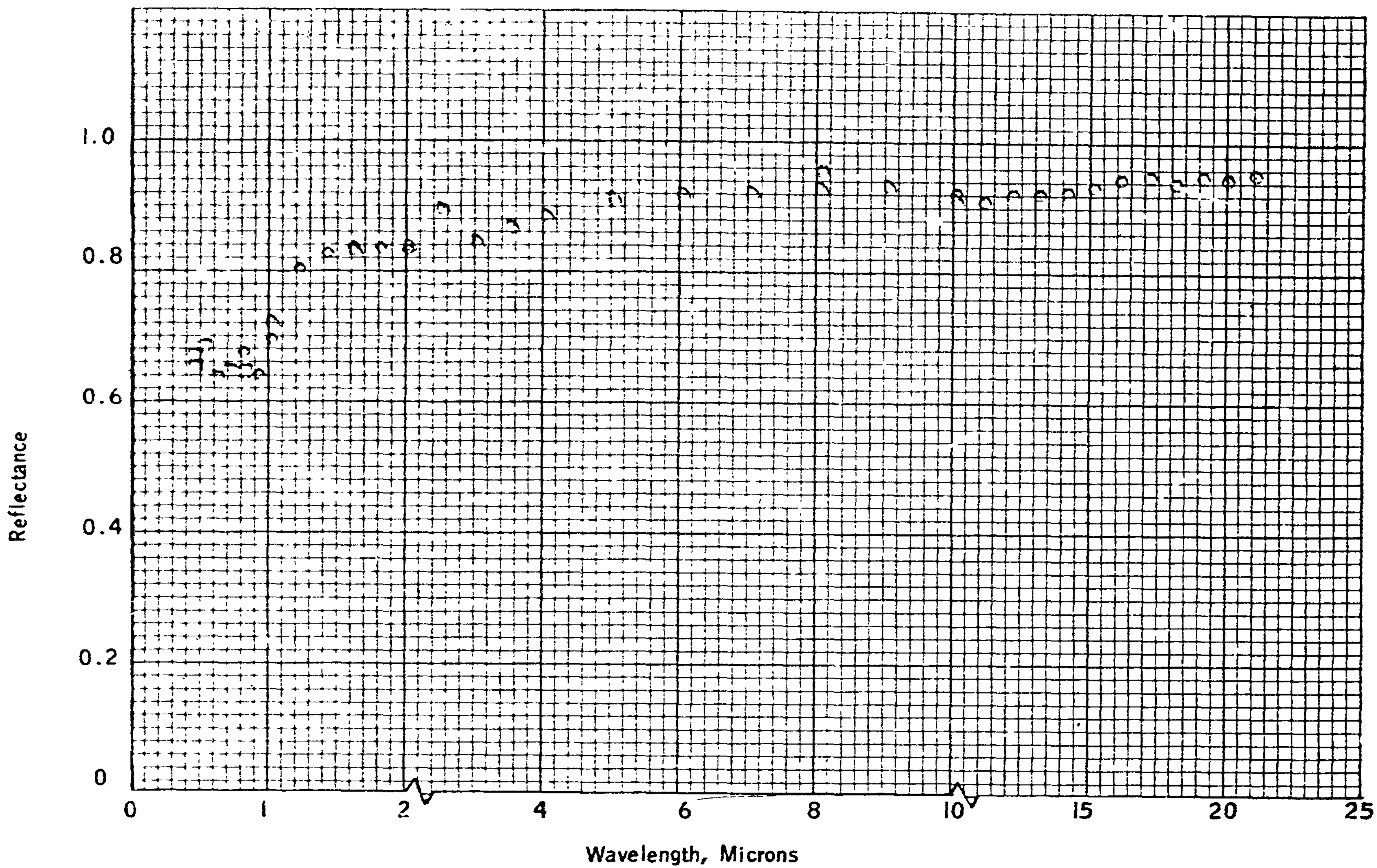


Fig. 89 Normal Spectral Reflectance of Specimen No 58 Temperature RT, HT-800F

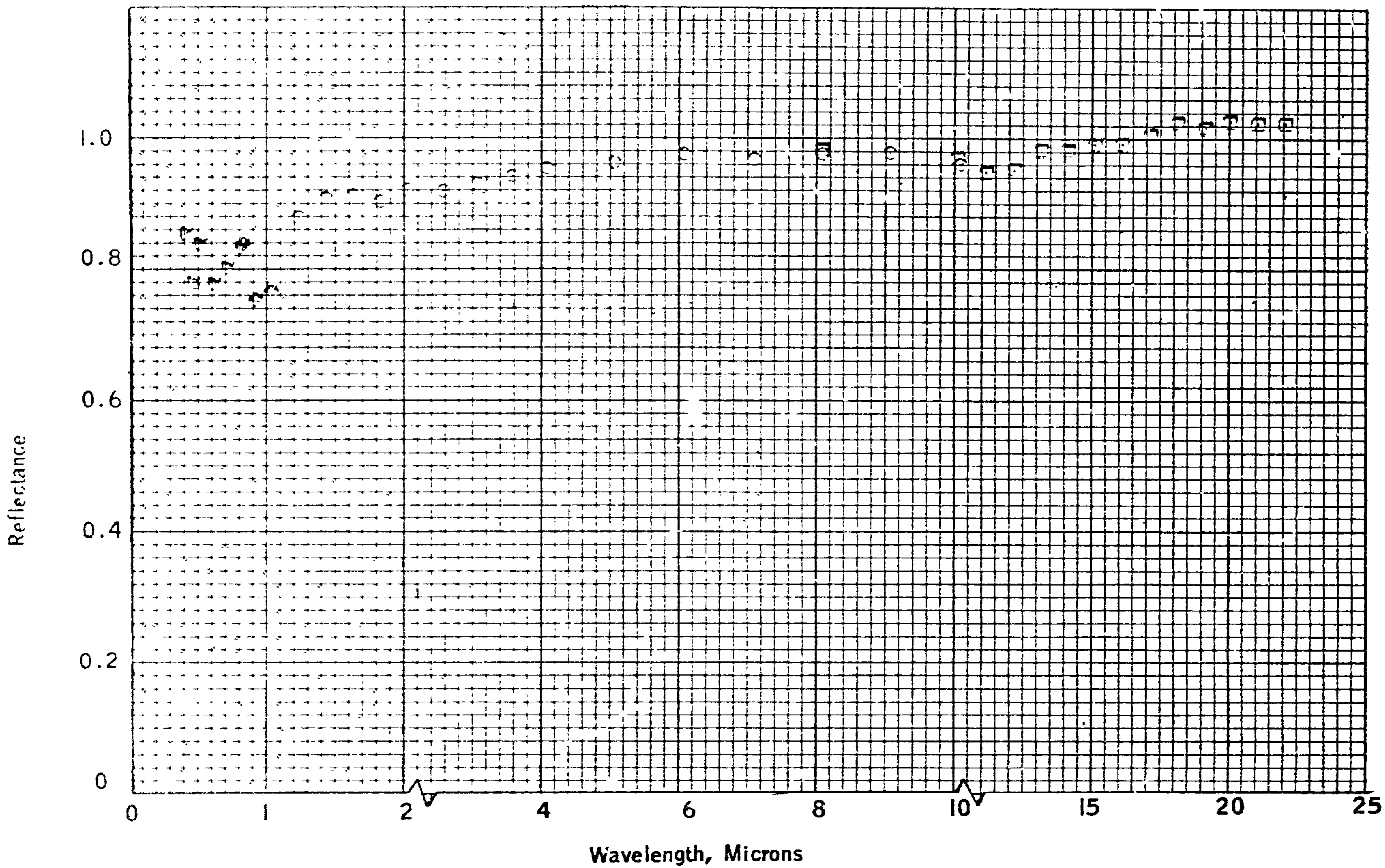


Fig. 90 Normal Spectral Reflectance of Specimen No 59 Temperature RT

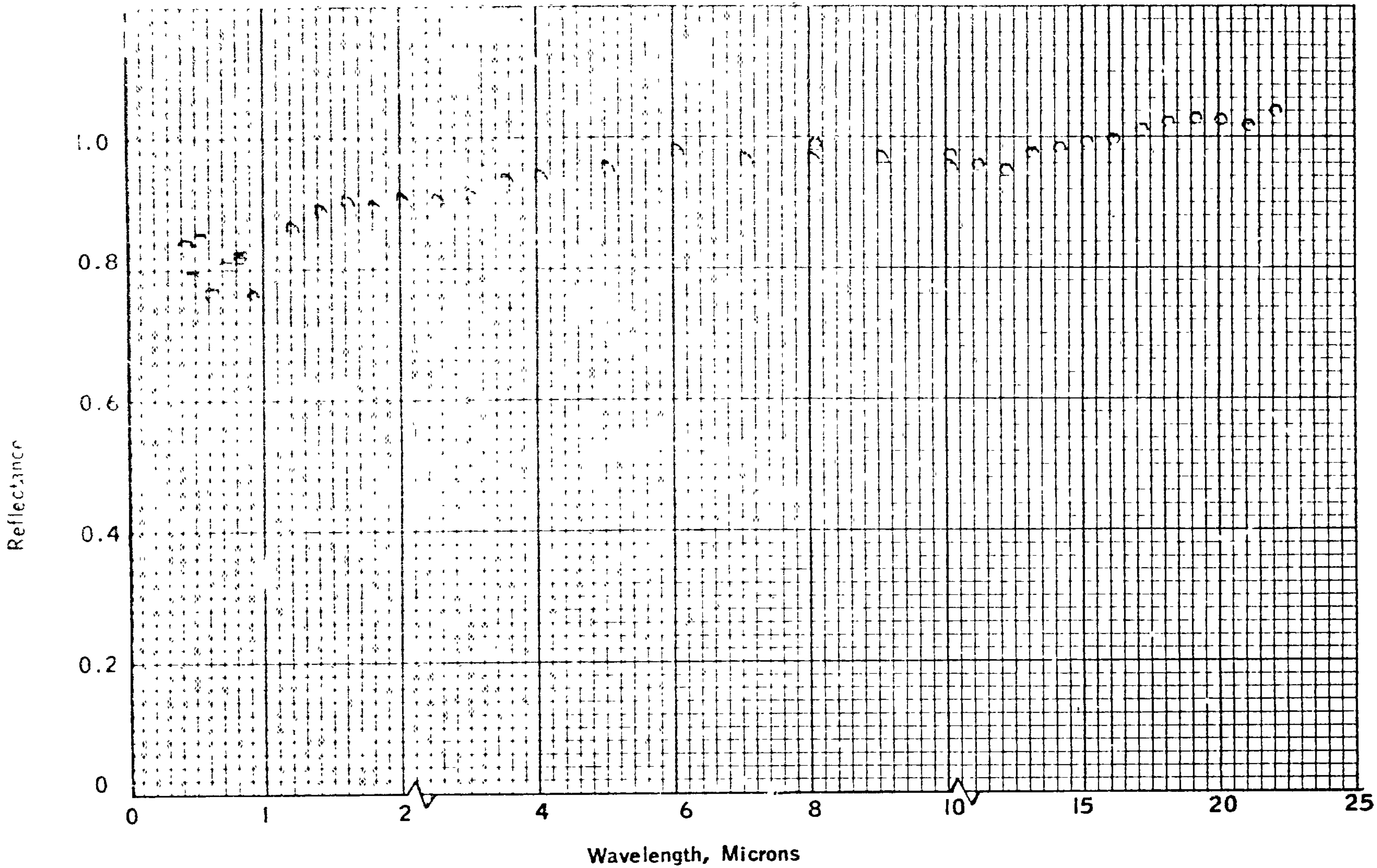


Fig. 91 Normal Spectral Reflectance of Specimen No 59 Temperature 300 F

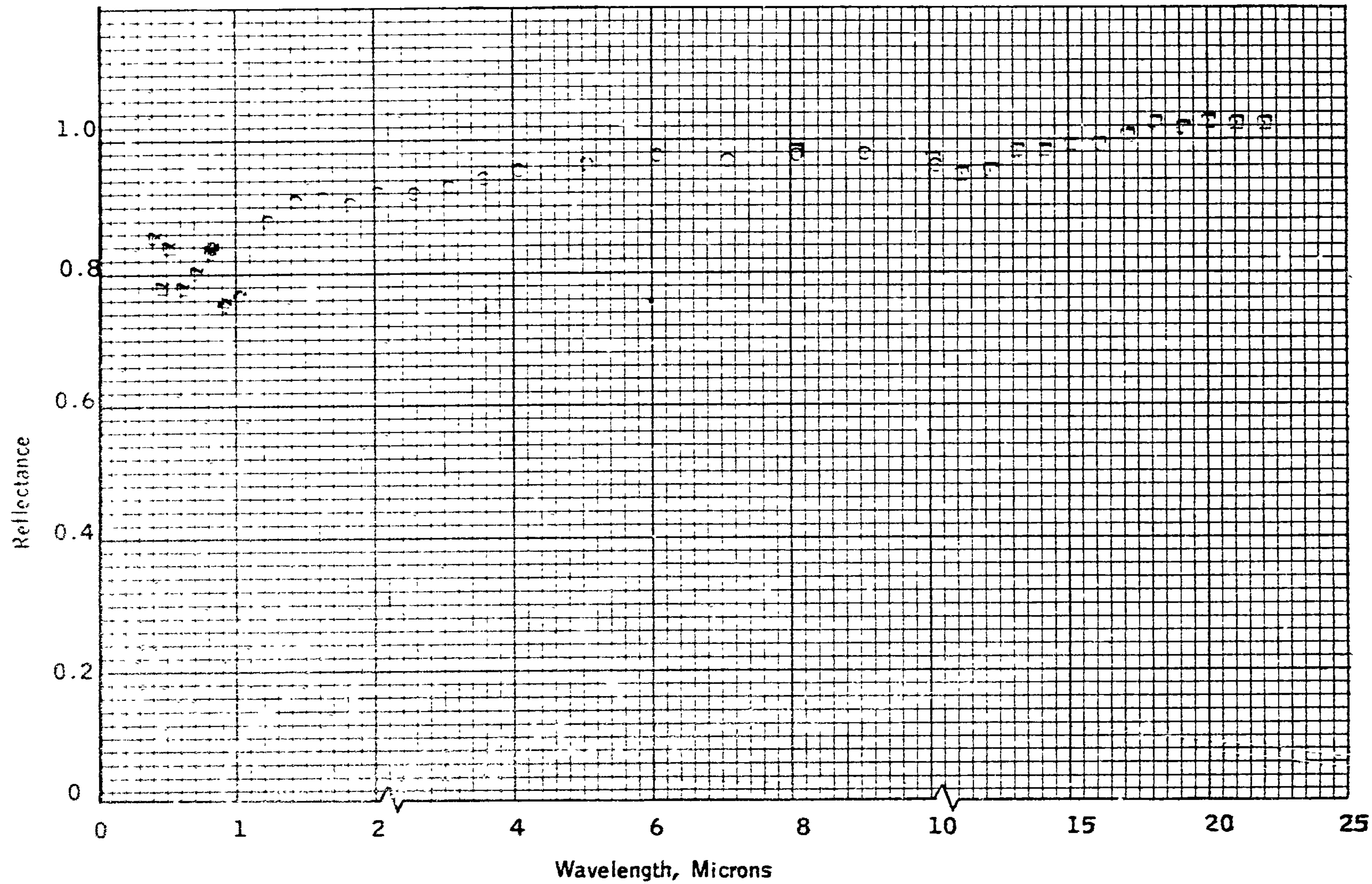


Fig. 92 Normal Spectral Reflectance of Specimen No 59 Temperature 600 F

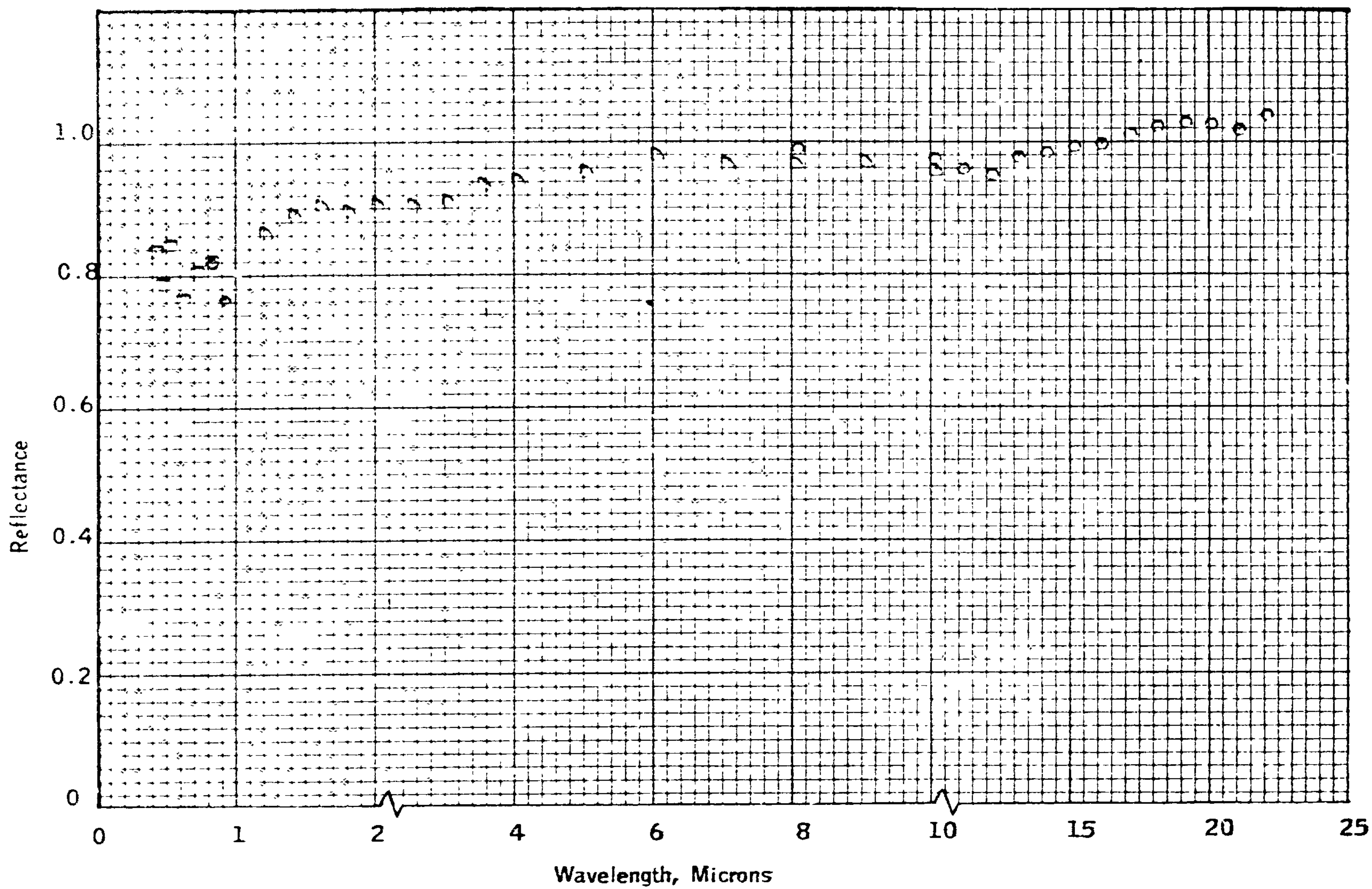


Fig. 93 Normal Spectral Reflectance of Specimen No 59 Temperature 825 F

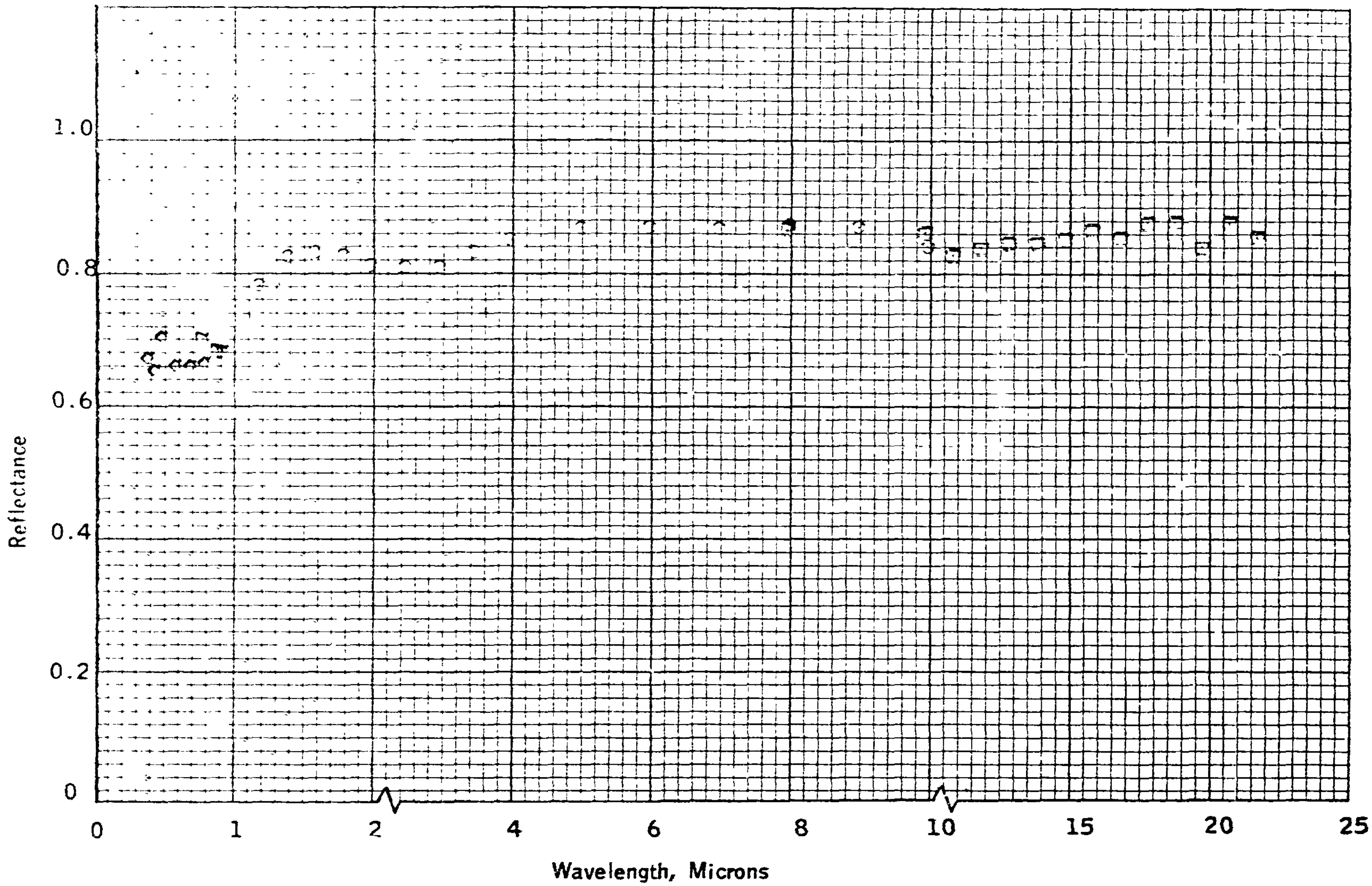


Fig. 94 Normal Spectral Reflectance of Specimen No 59 Temperature RT_f

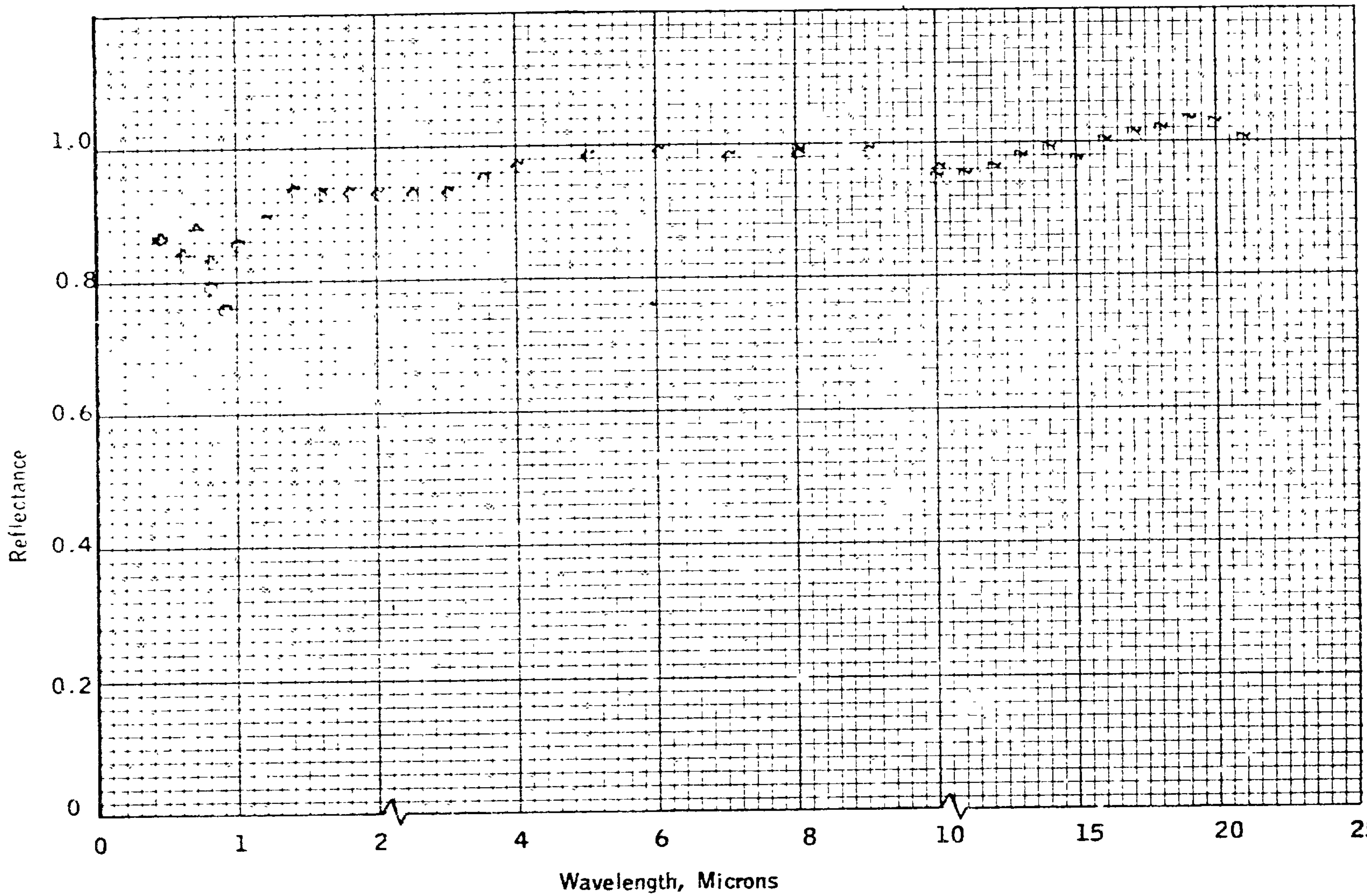


Fig. 95 Normal Spectral Reflectance of Specimen No 60 Temperature RT

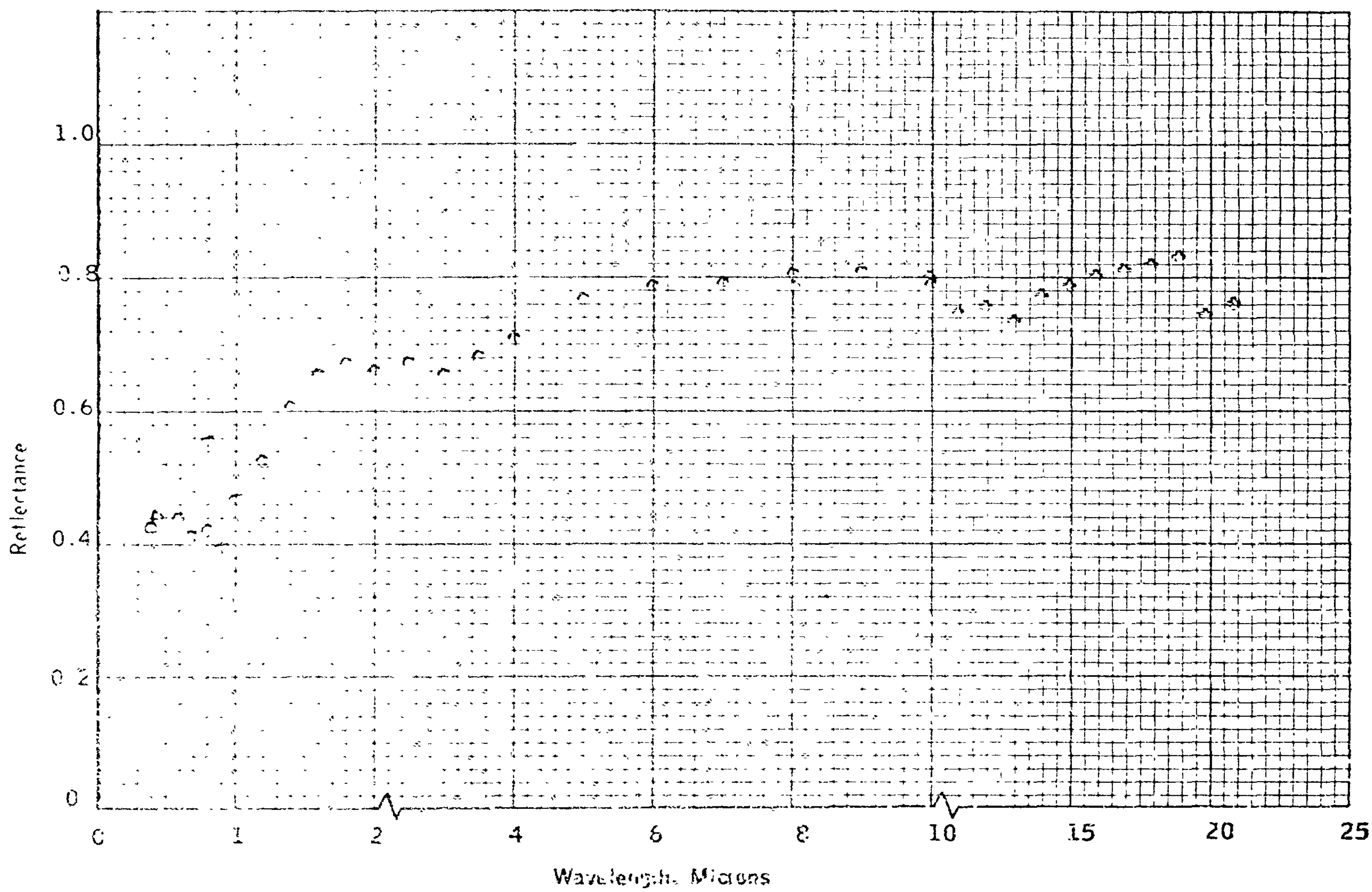


Fig. 96 Normal Spectral Reflectance of Specimen No 79 Temperature RT

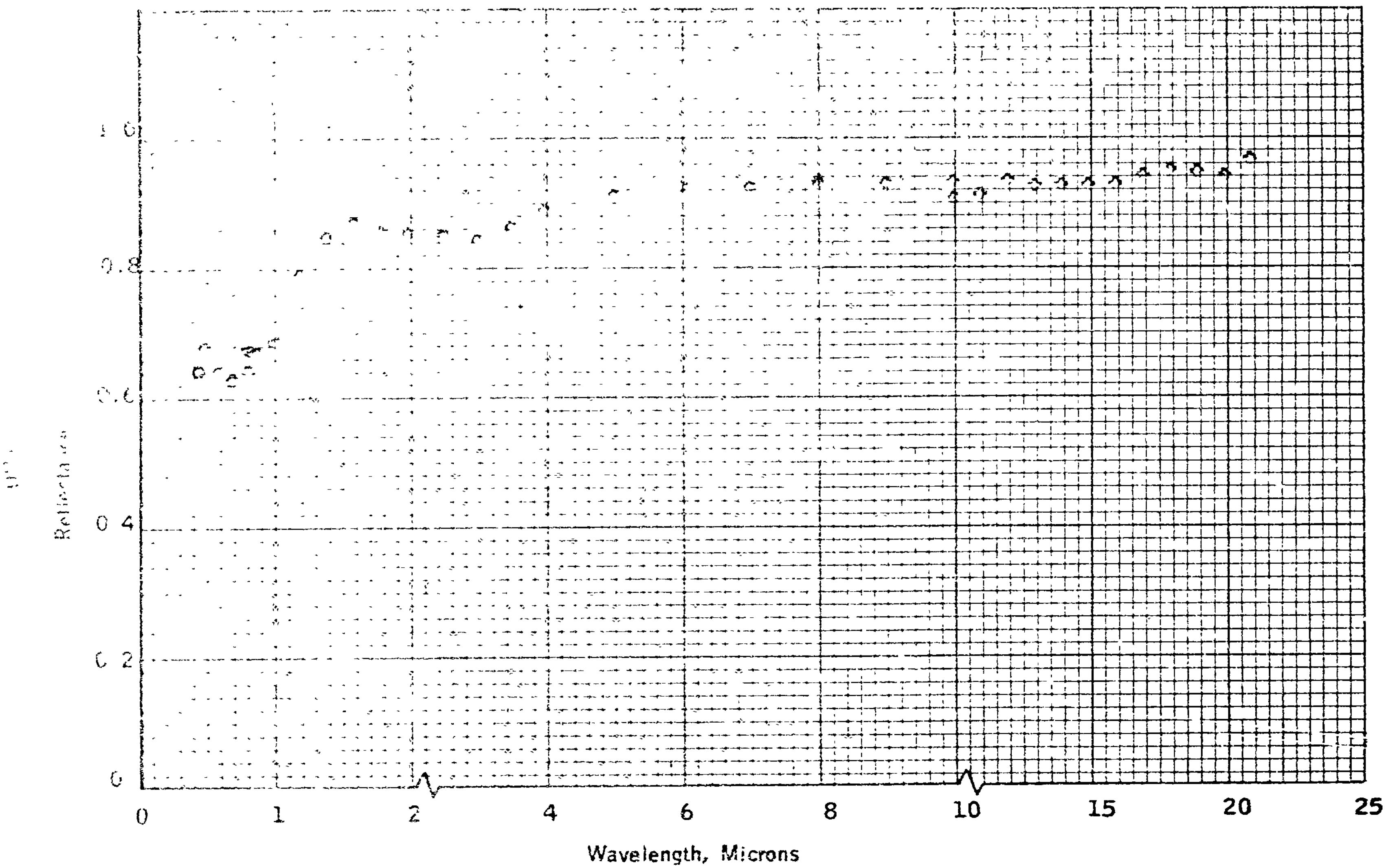


Fig. 97 Normal Spectral Reflectance of Specimen No 100 Temperature RT

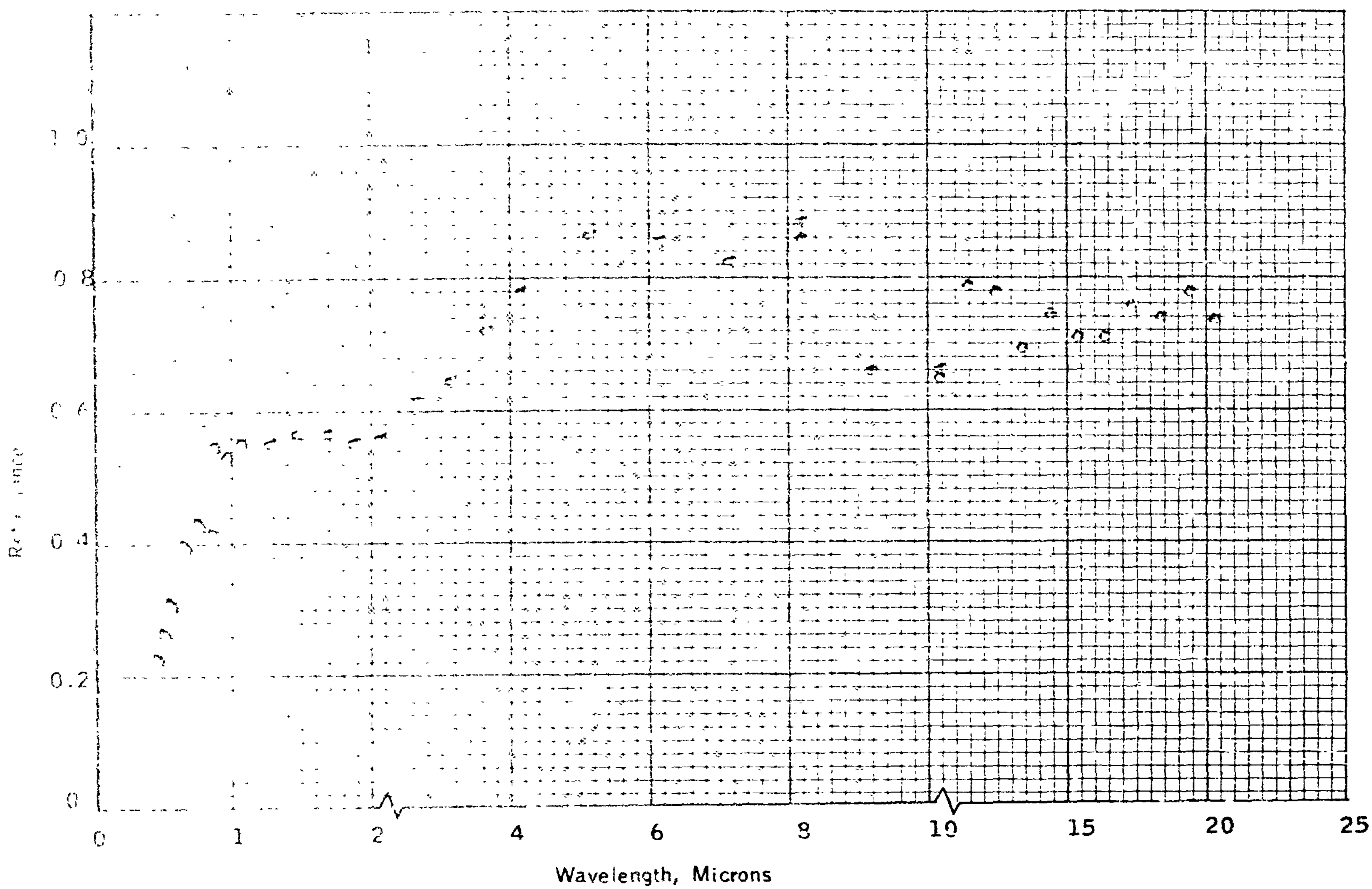


Fig. 98 Normal Spectral Reflectance of Specimen No 25 Temperature RT

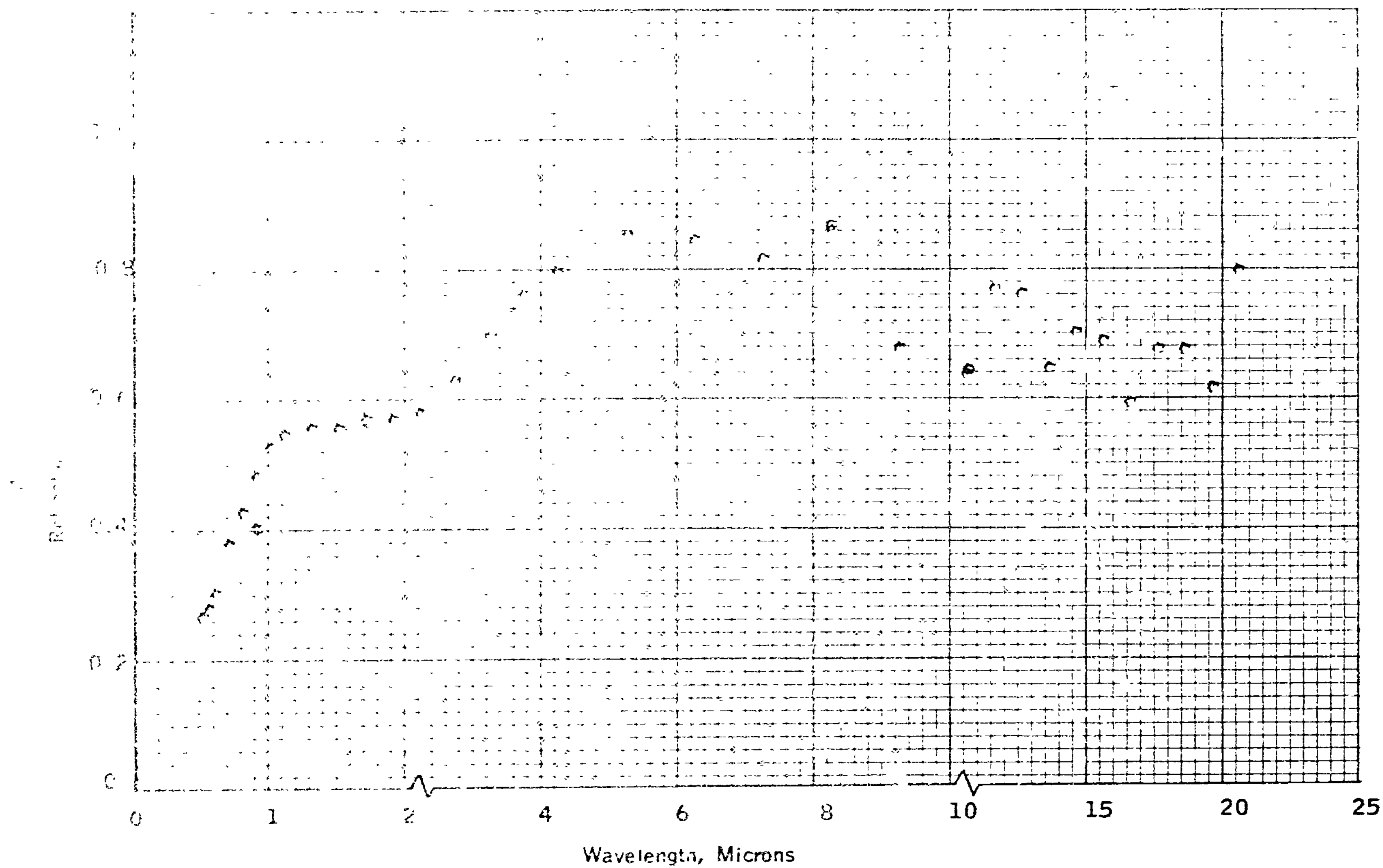


Fig. 99 Normal Spectral Reflectance of Specimen No 25 Temperature 350 F

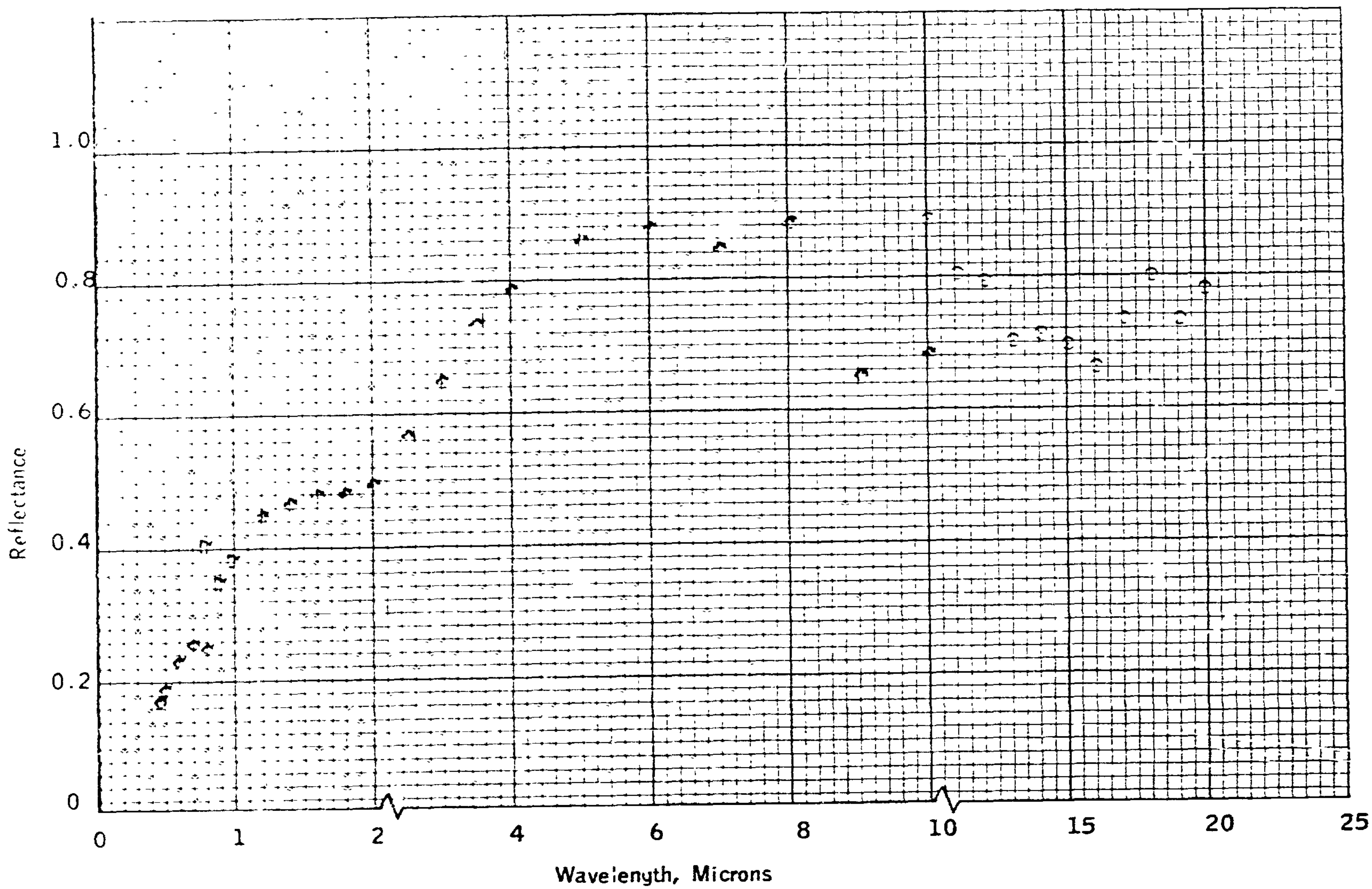


Fig. 100 Normal Spectral Reflectance of Specimen No 25 Temperature RT HT-800F

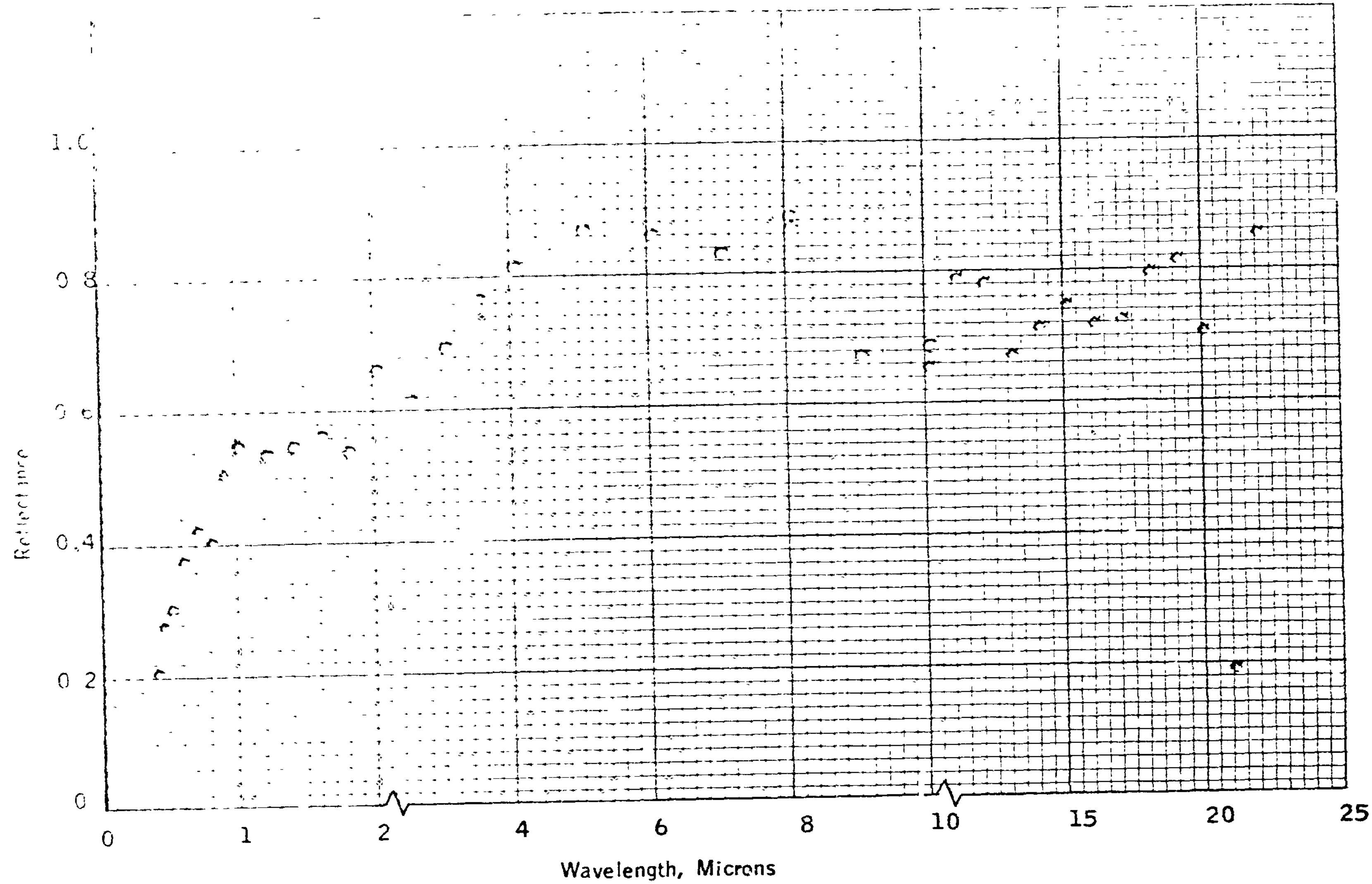


Fig. 101 Normal Spectral Reflectance of Specimen No 25 Temperature RT_f

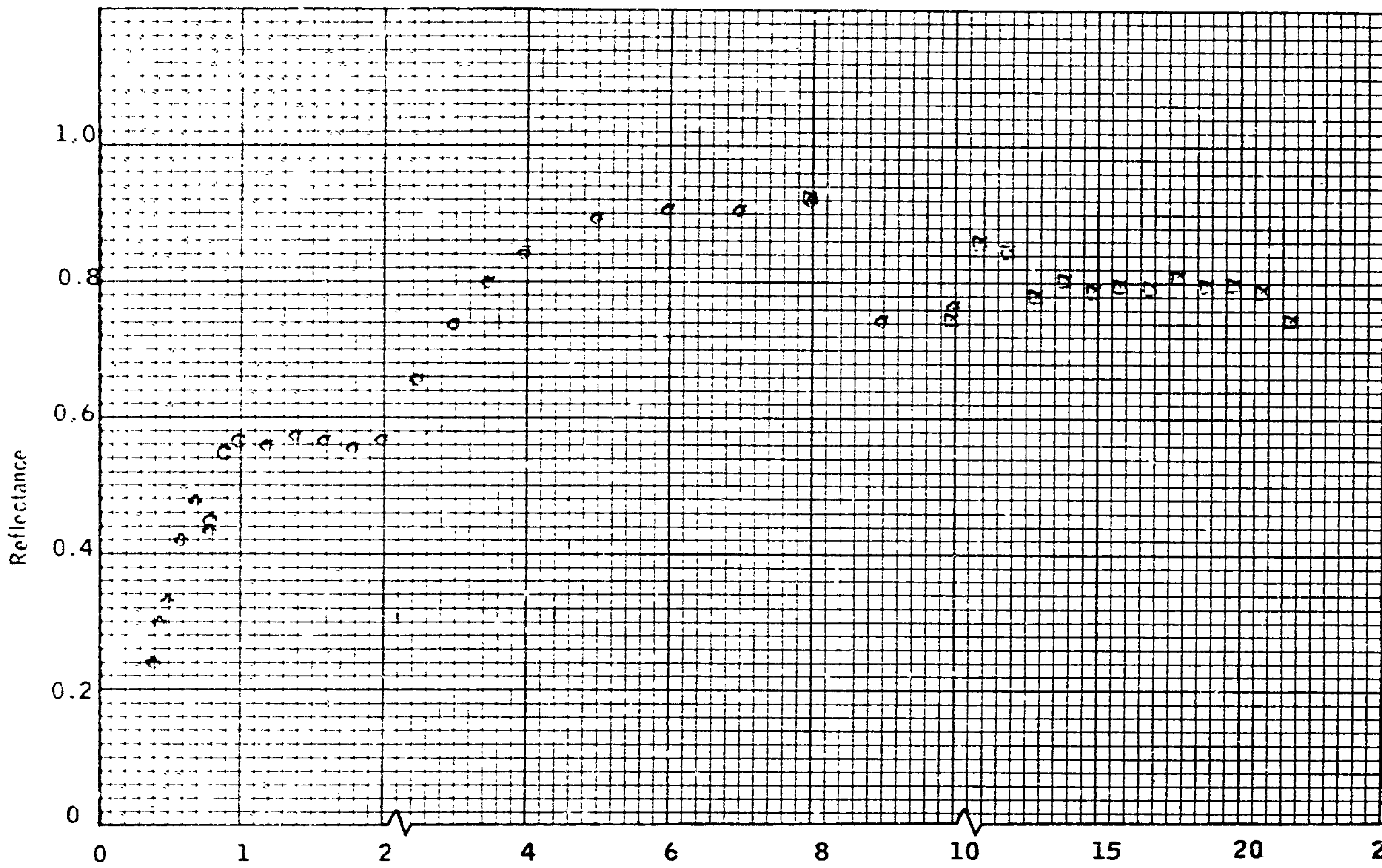


Fig. 102 Normal Spectral Reflectance of Specimen No 36 Temperature RT

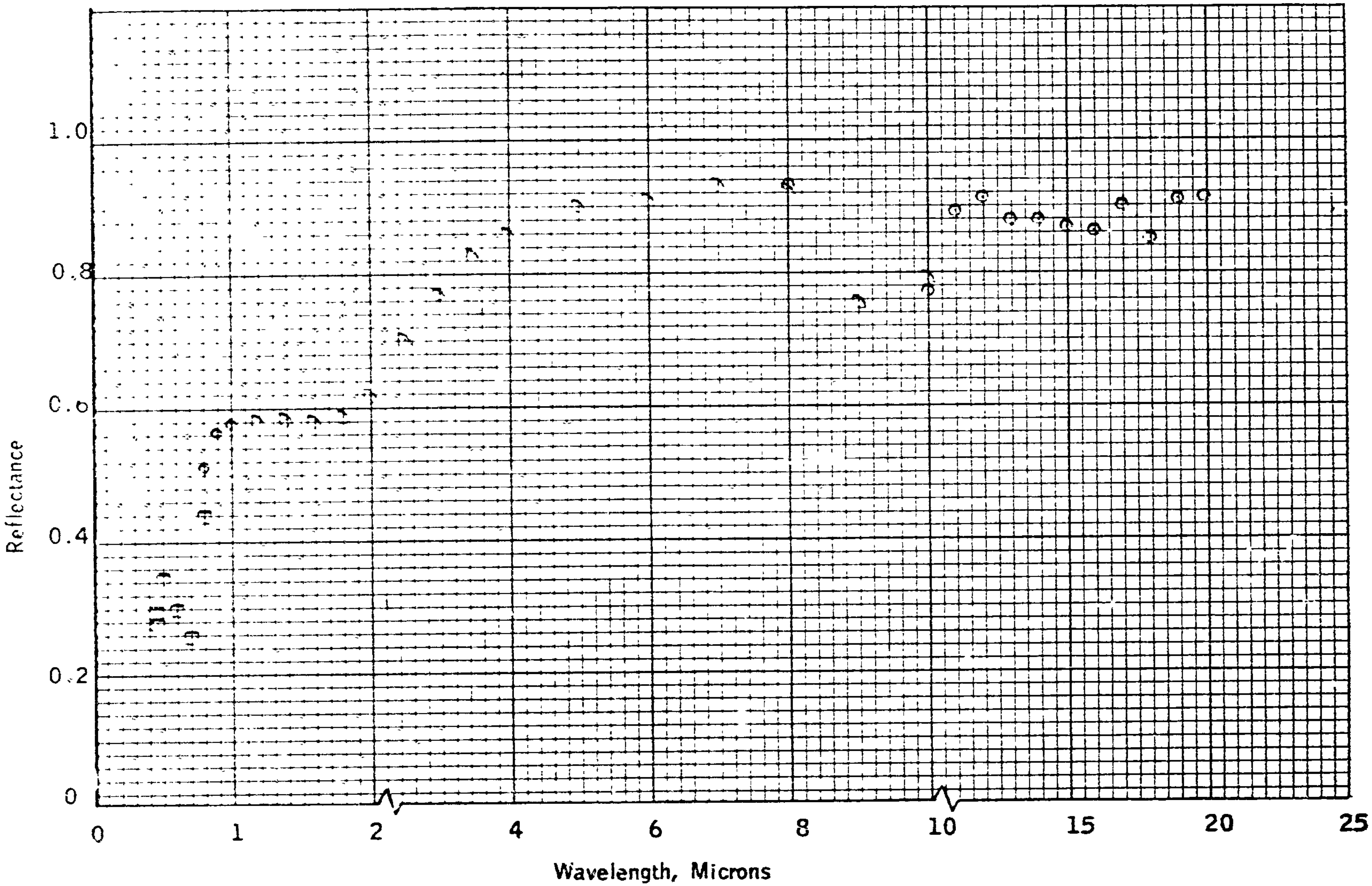


Fig. 103 Normal Spectral Reflectance of Specimen No 138 Temperature RT

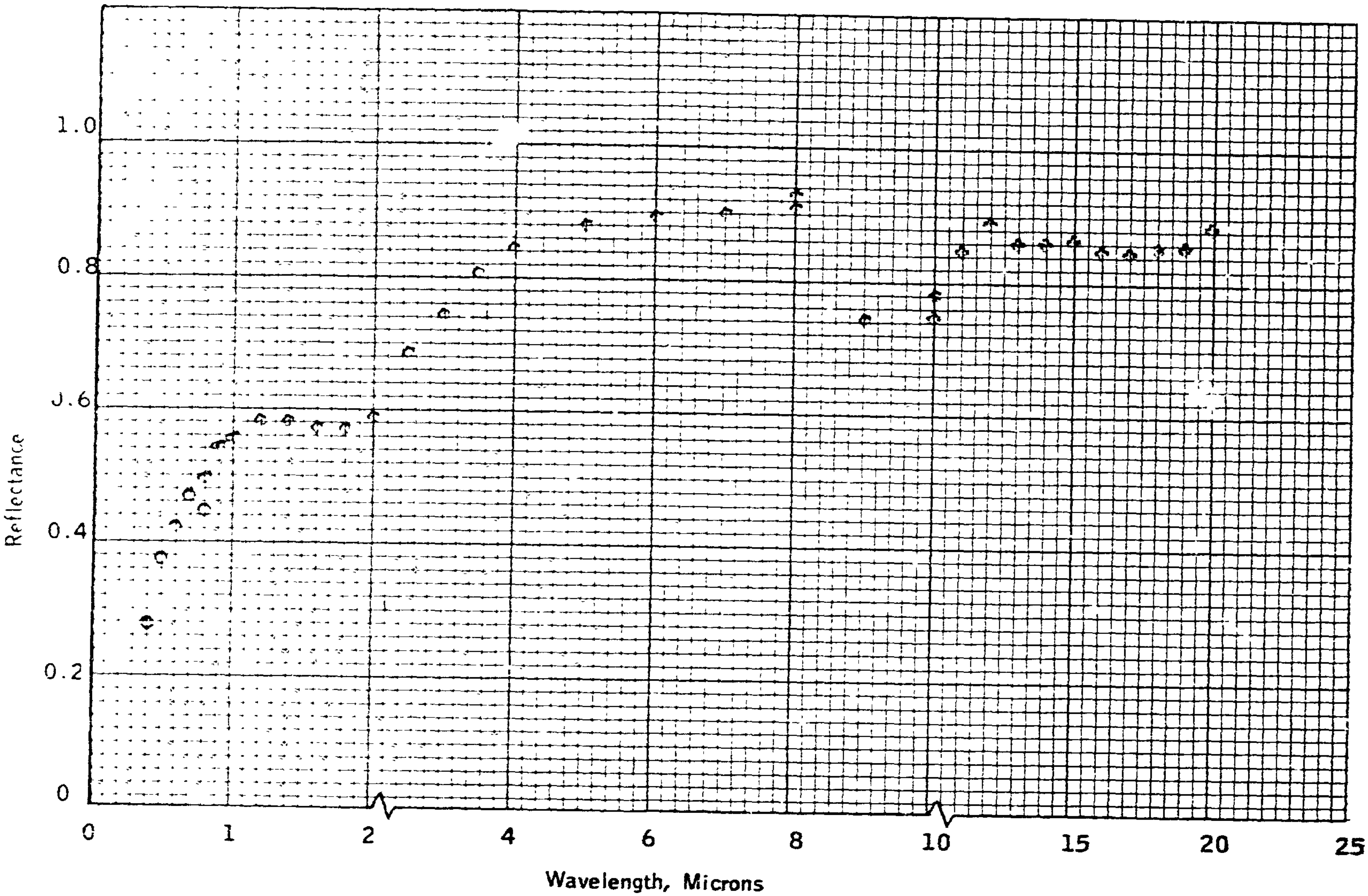


Fig. 104 Normal Spectral Reflectance of Specimen No 138 Temperature RT, MF

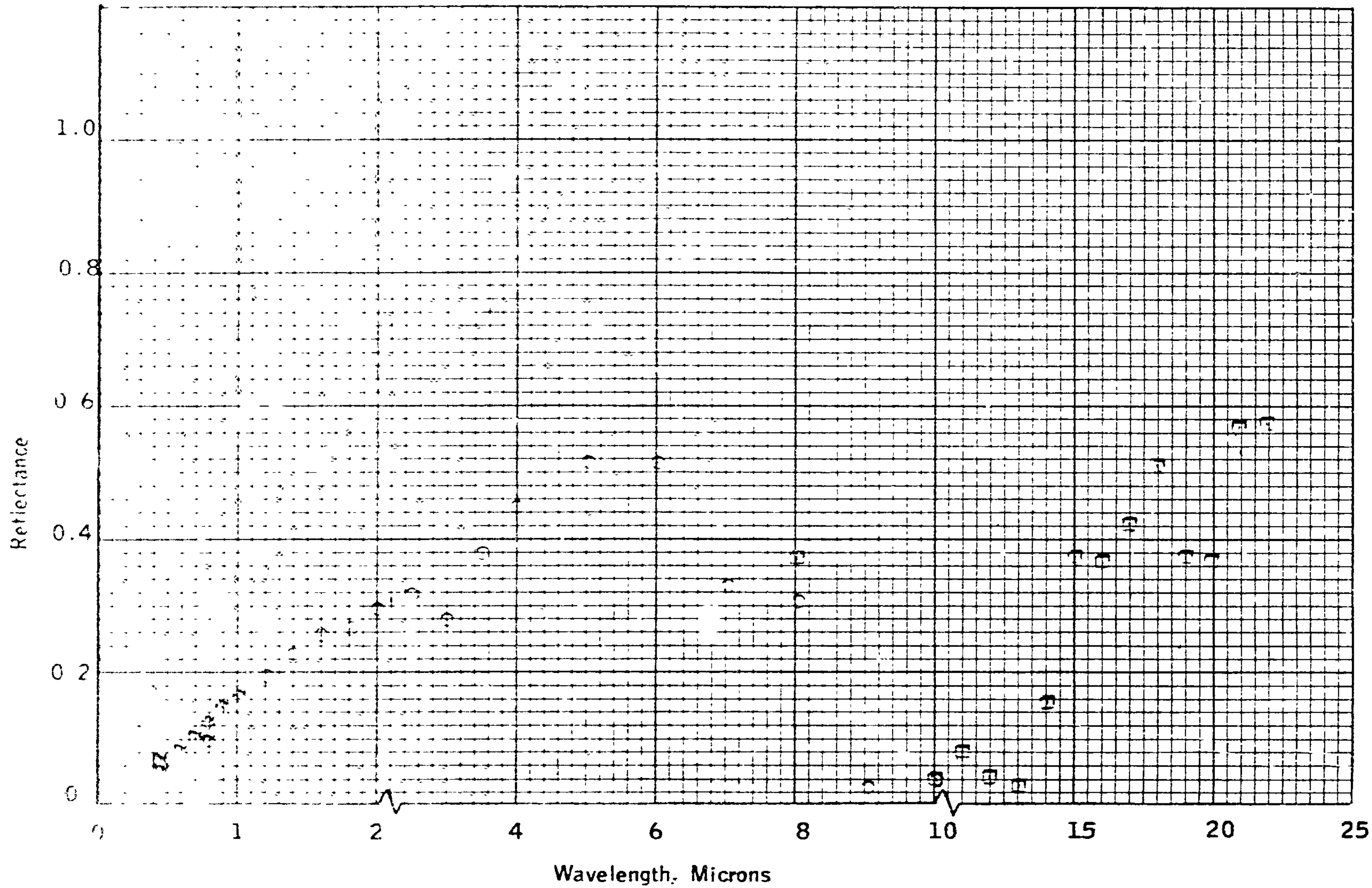


Fig. 105 Normal Spectral Reflectance of Specimen No 140 Temperature RT

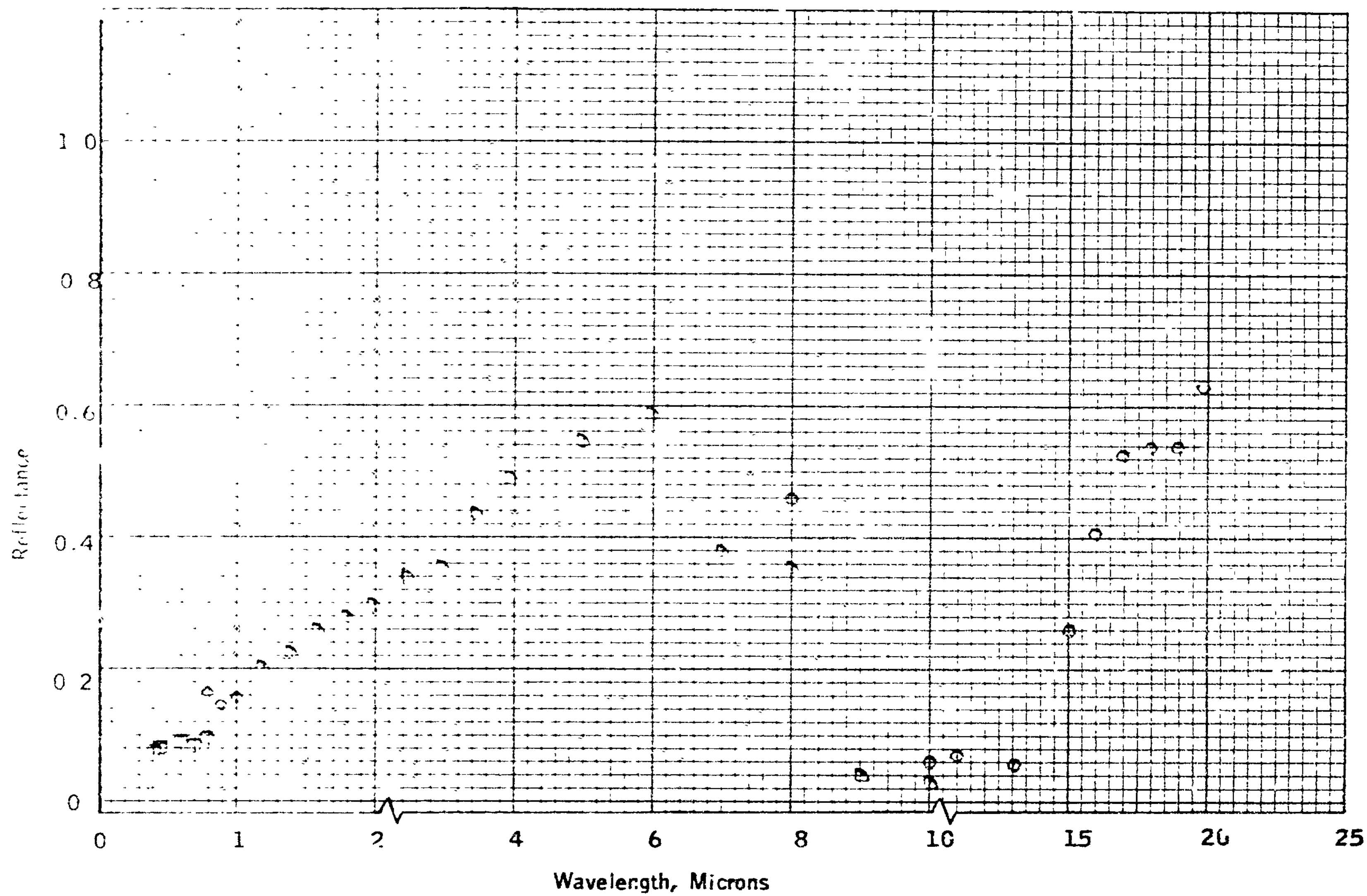


Fig. 106 Normal Spectral Reflectance of Specimen No 140 Temperature RT, HT-800F

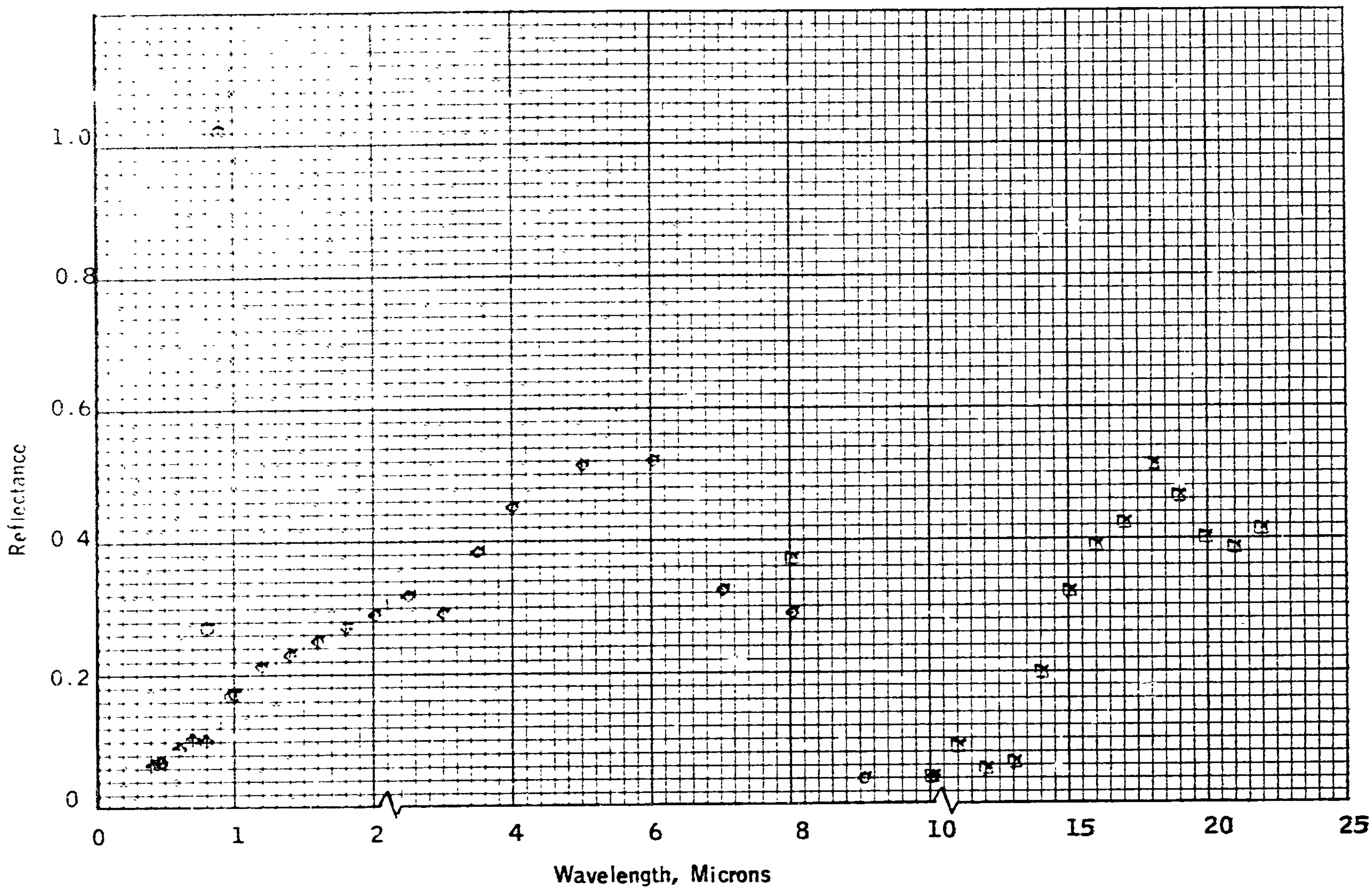


Fig. 107 Normal Spectral Reflectance of Specimen No 140 Temperature RT, MF

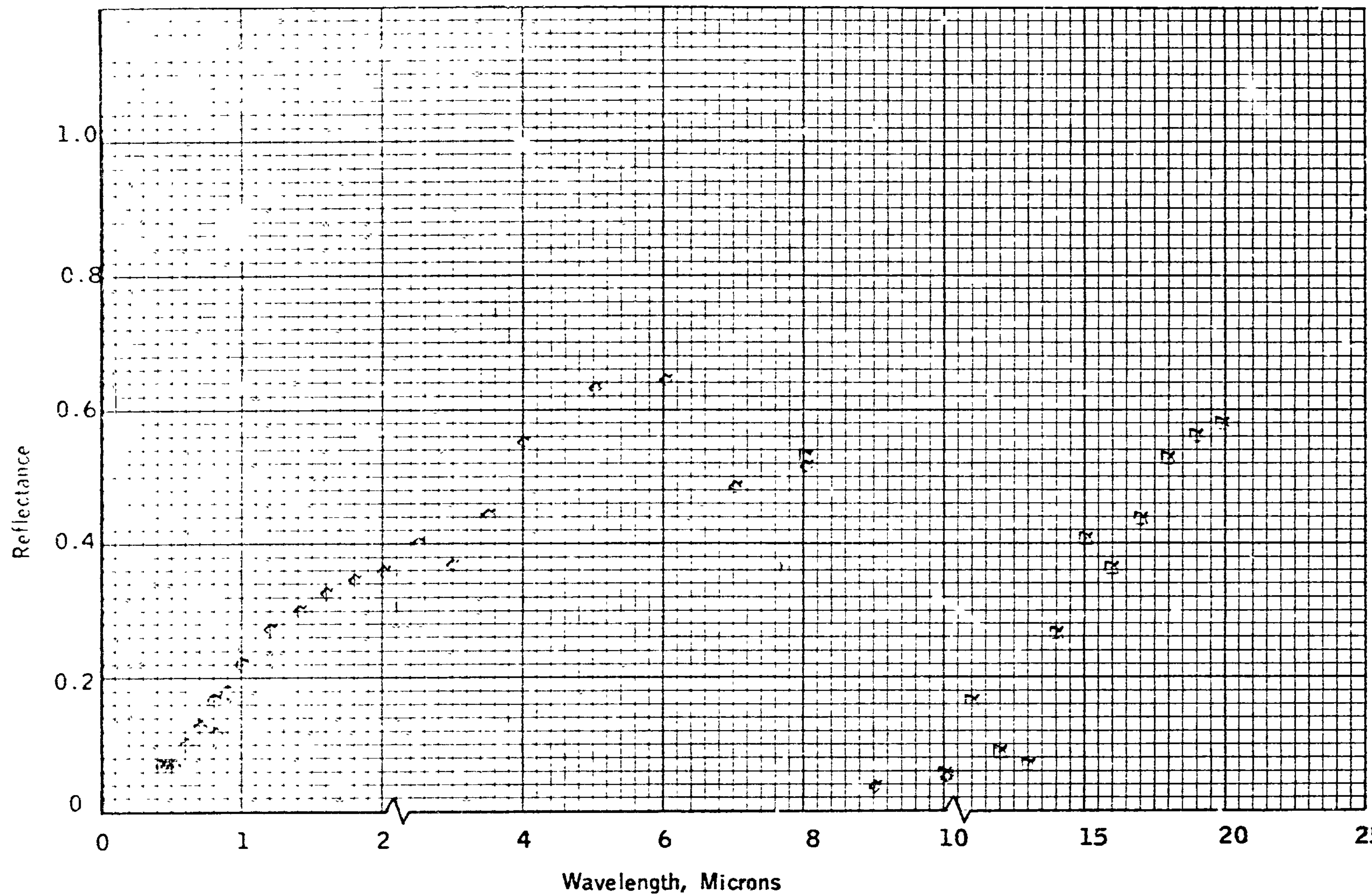


Fig. 108 Normal Spectral Reflectance of Specimen No 155 Temperature RT

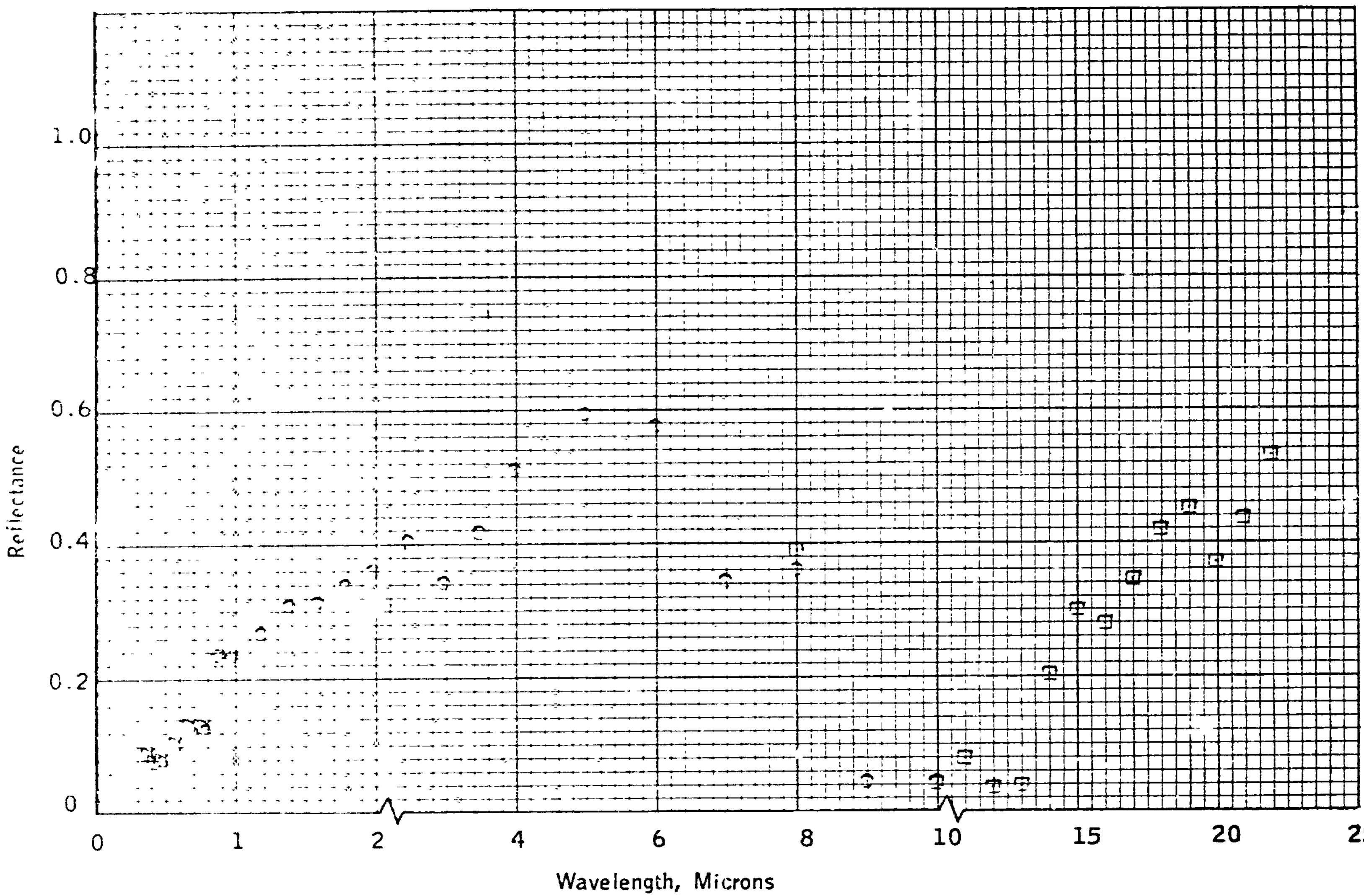


Fig. 109 Normal Spectral Reflectance of Specimen No 210 Temperature RT

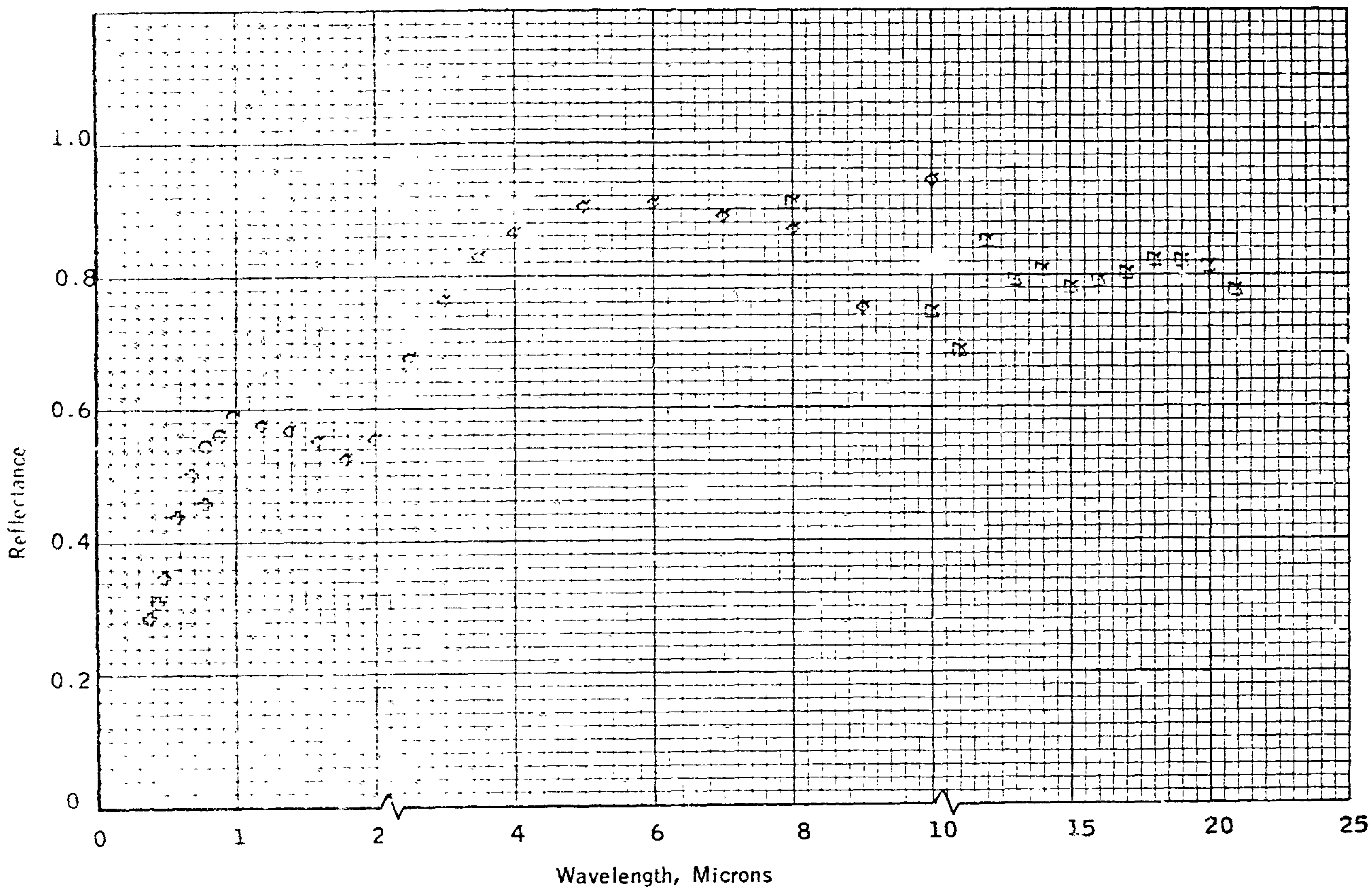


Fig. 110 Normal Spectral Reflectance of Specimen No 211 Temperature RT

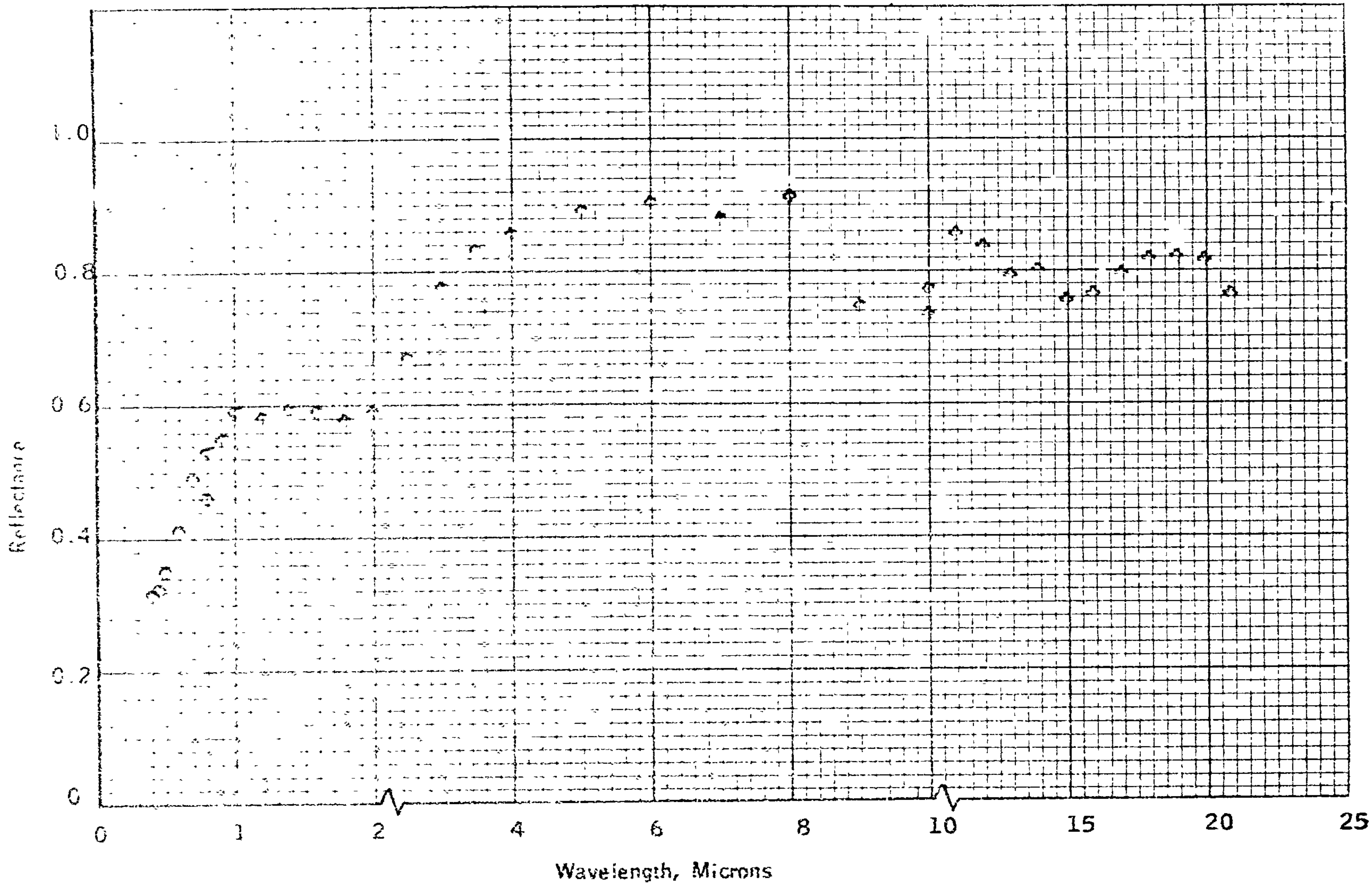


Fig. 111 Normal Spectral Reflectance of Specimen No 211 Temperature 350F

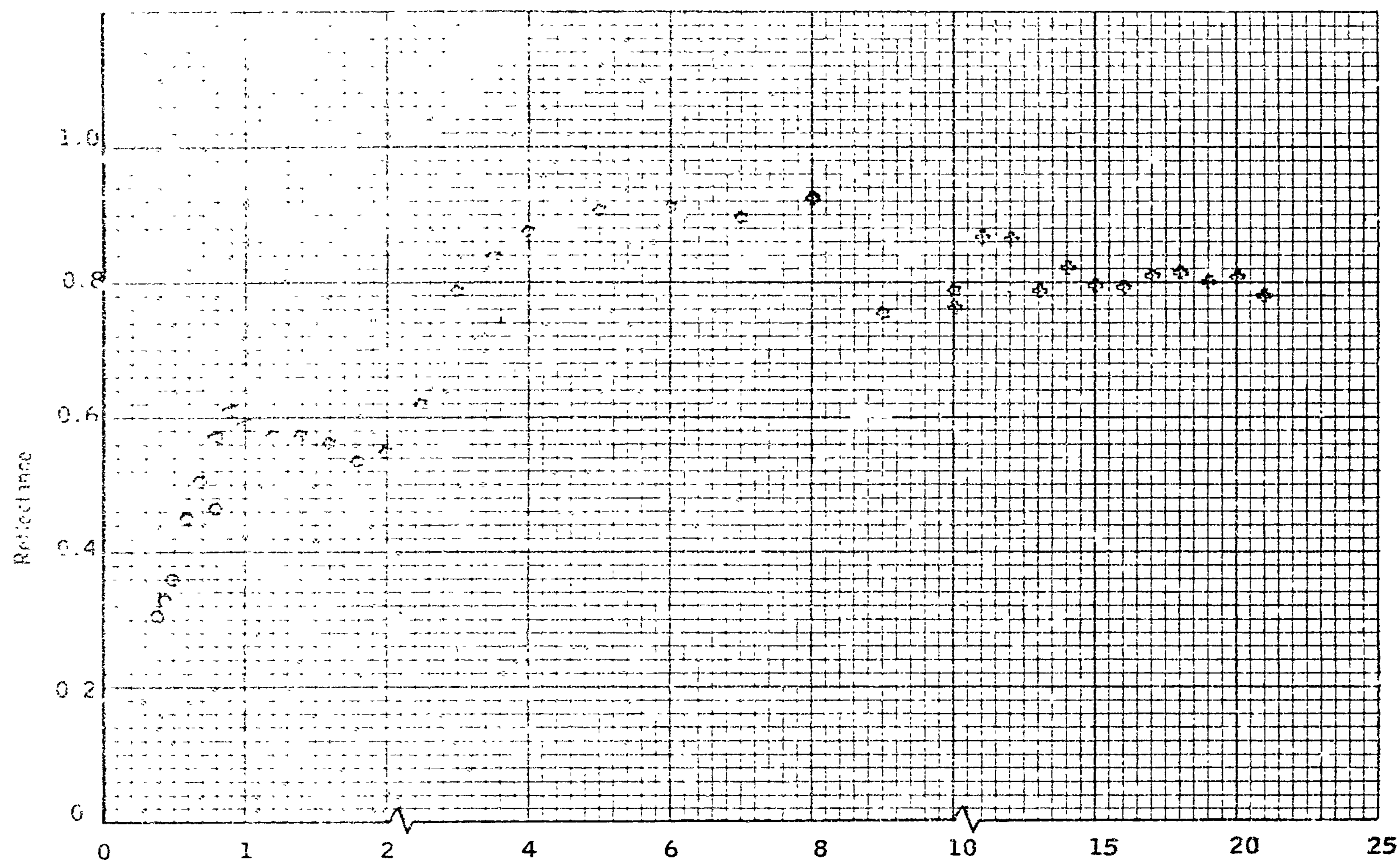


Fig.112 Normal Spectral Reflectance of Specimen No 211 Temperature RT_f

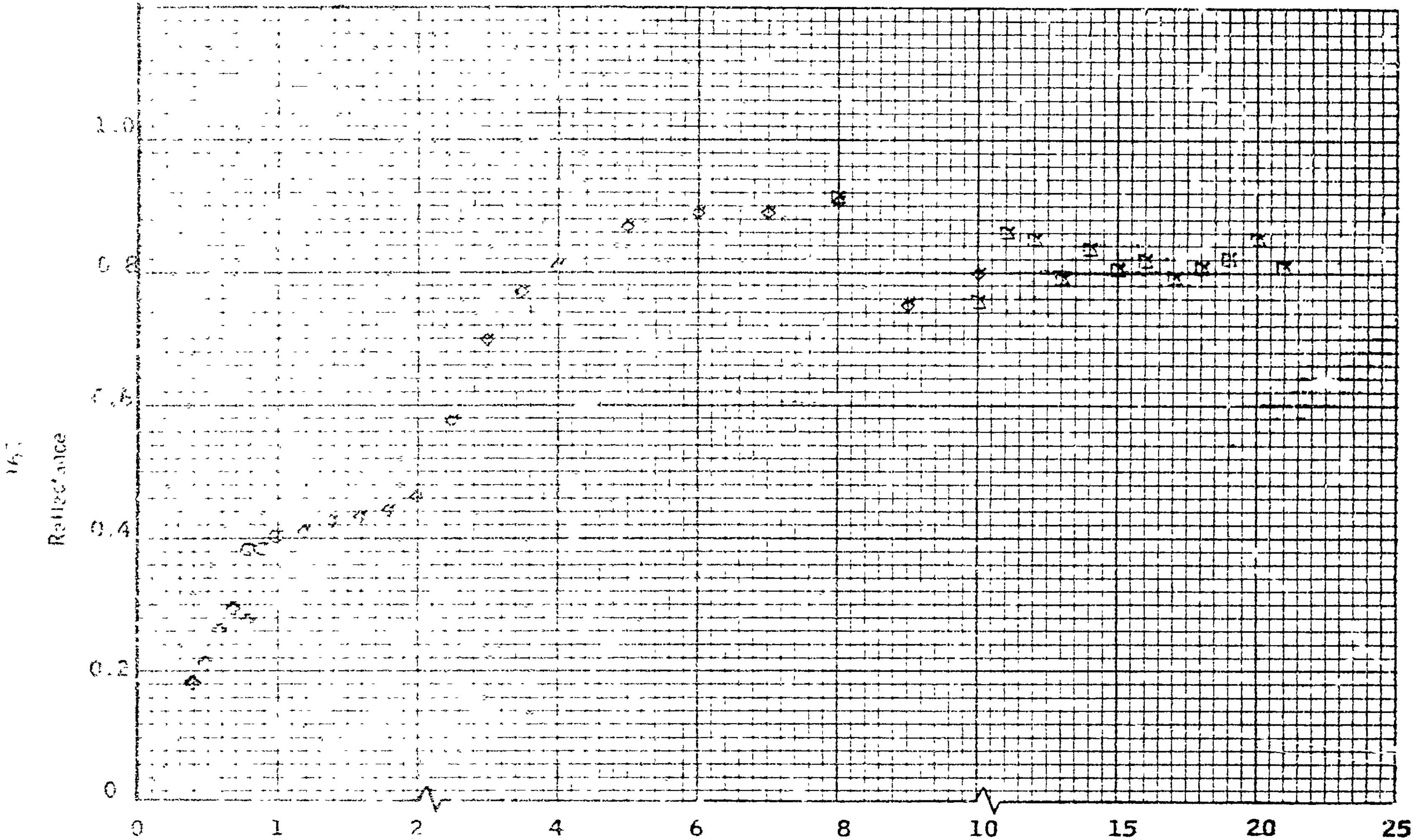


Fig 113 Normal Spectral Reflectance of Specimen No 211 Temperature RT, HT-800F

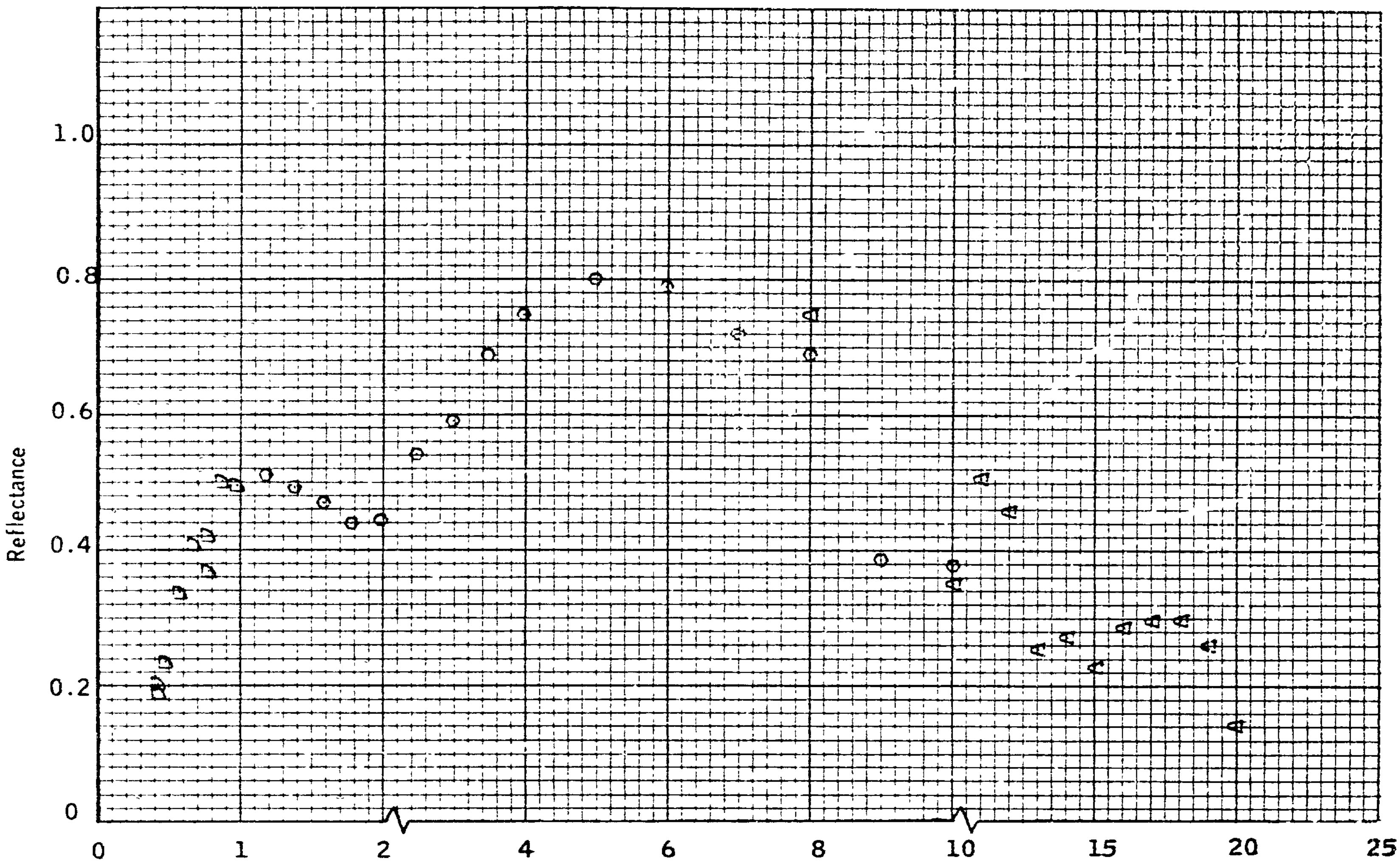


Fig. 114 Normal Spectral Reflectance of Specimen No 215 Temperature RT

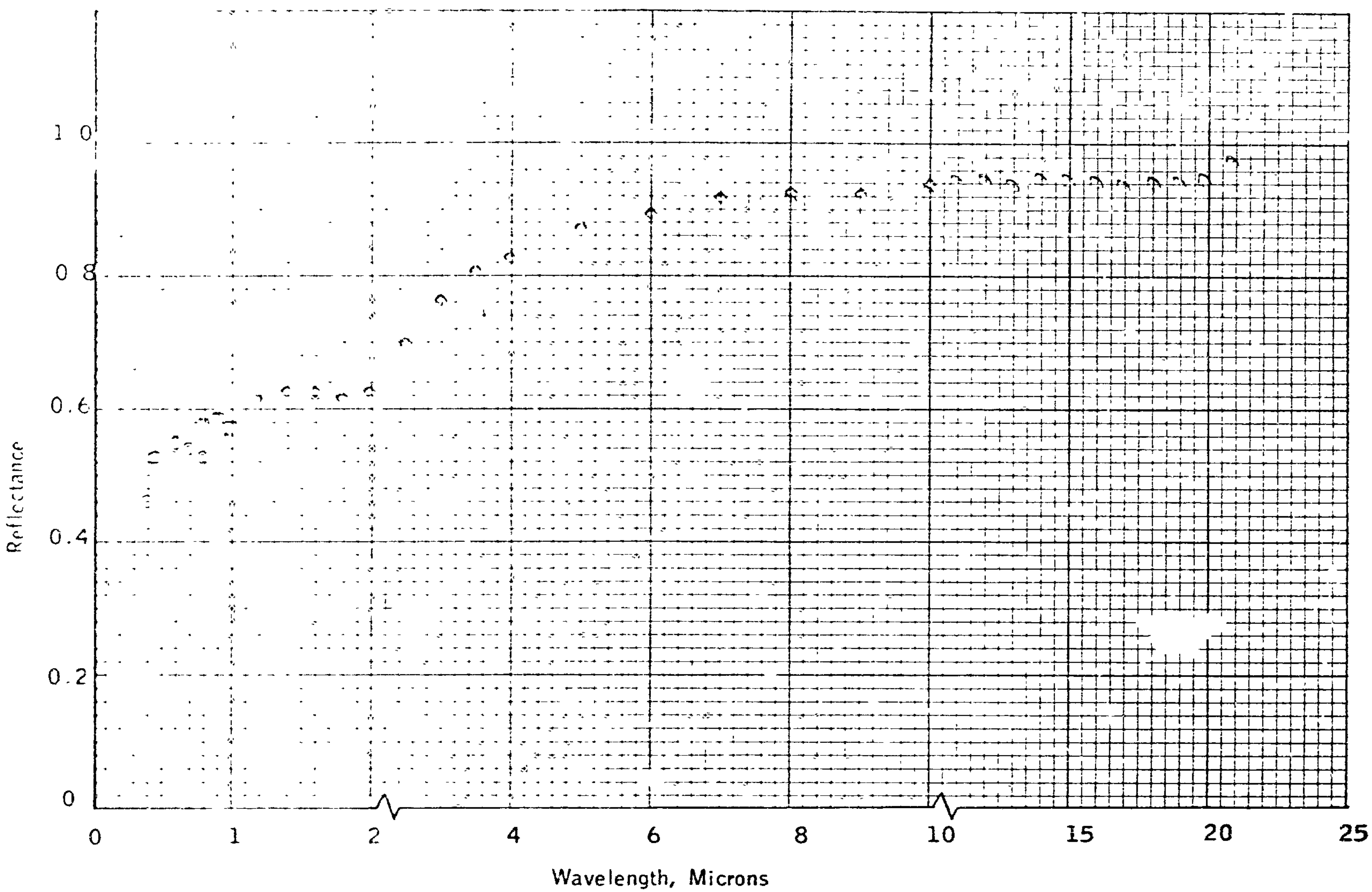


Fig. 115 Normal Spectral Reflectance of Specimen No 31 Temperature RT

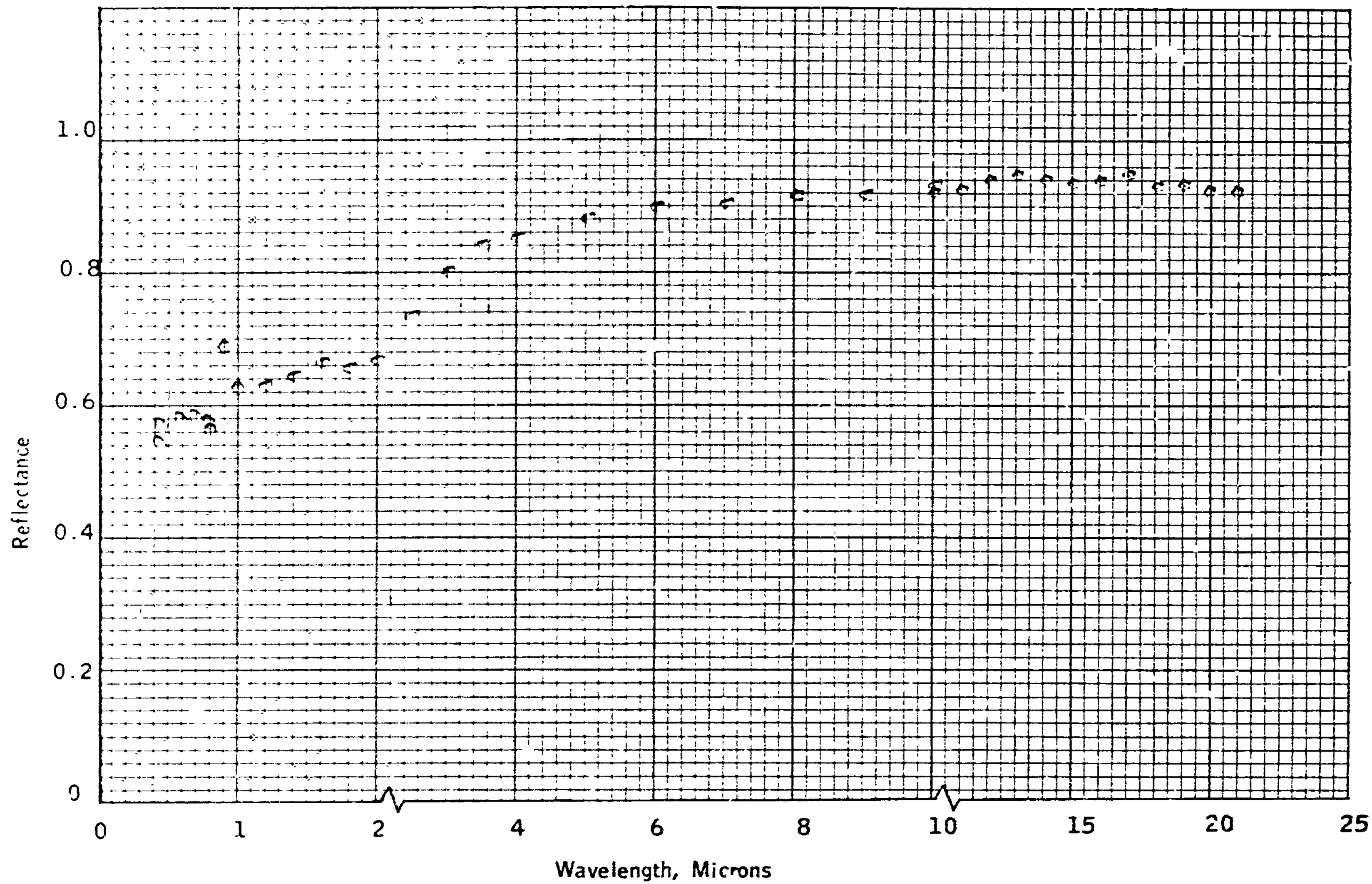


Fig. 116 Normal Spectral Reflectance of Specimen No 31 Temperature 350F

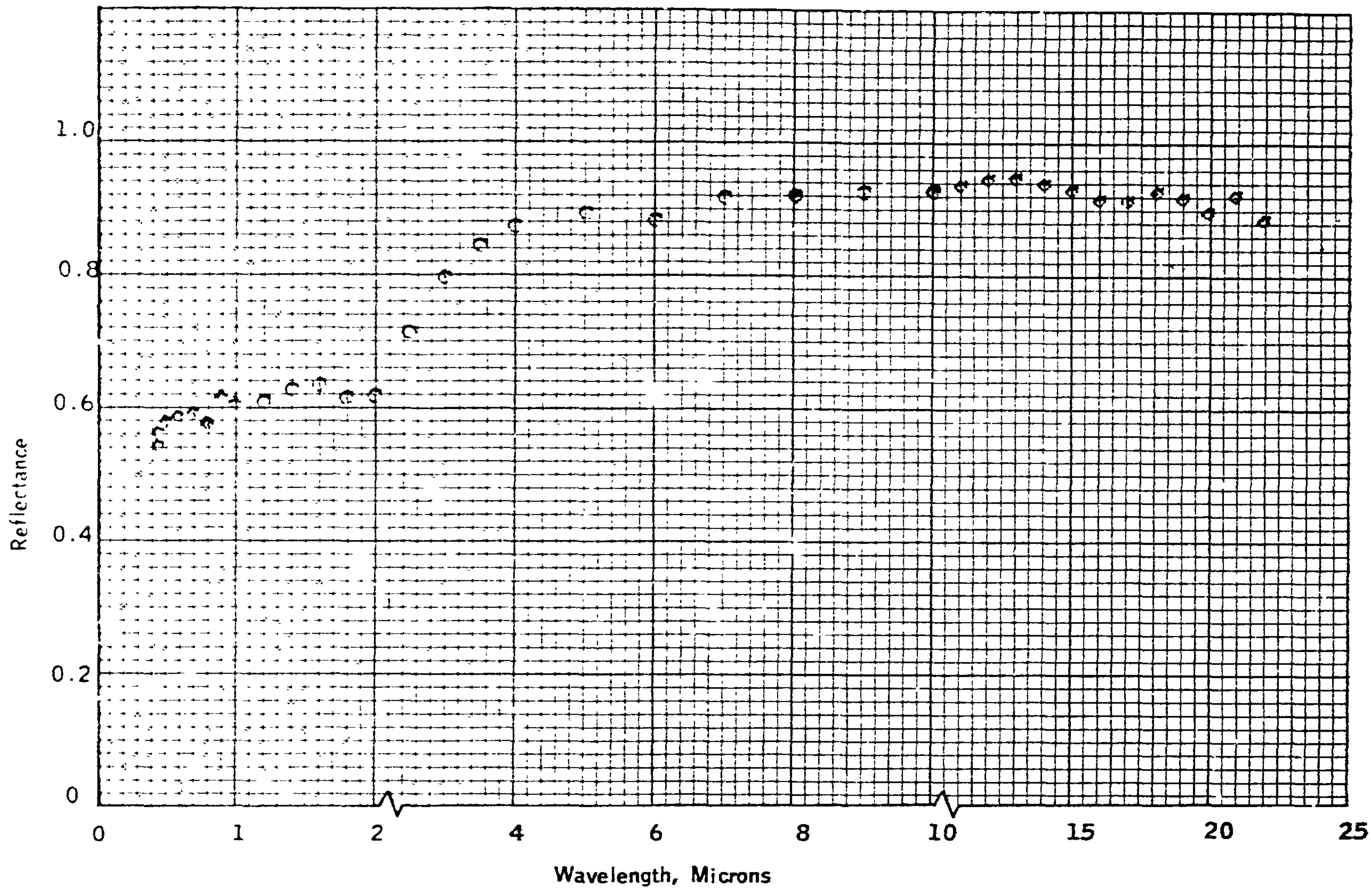


Fig. 117 Normal Spectral Reflectance of Specimen No 31 Temperature RT_f

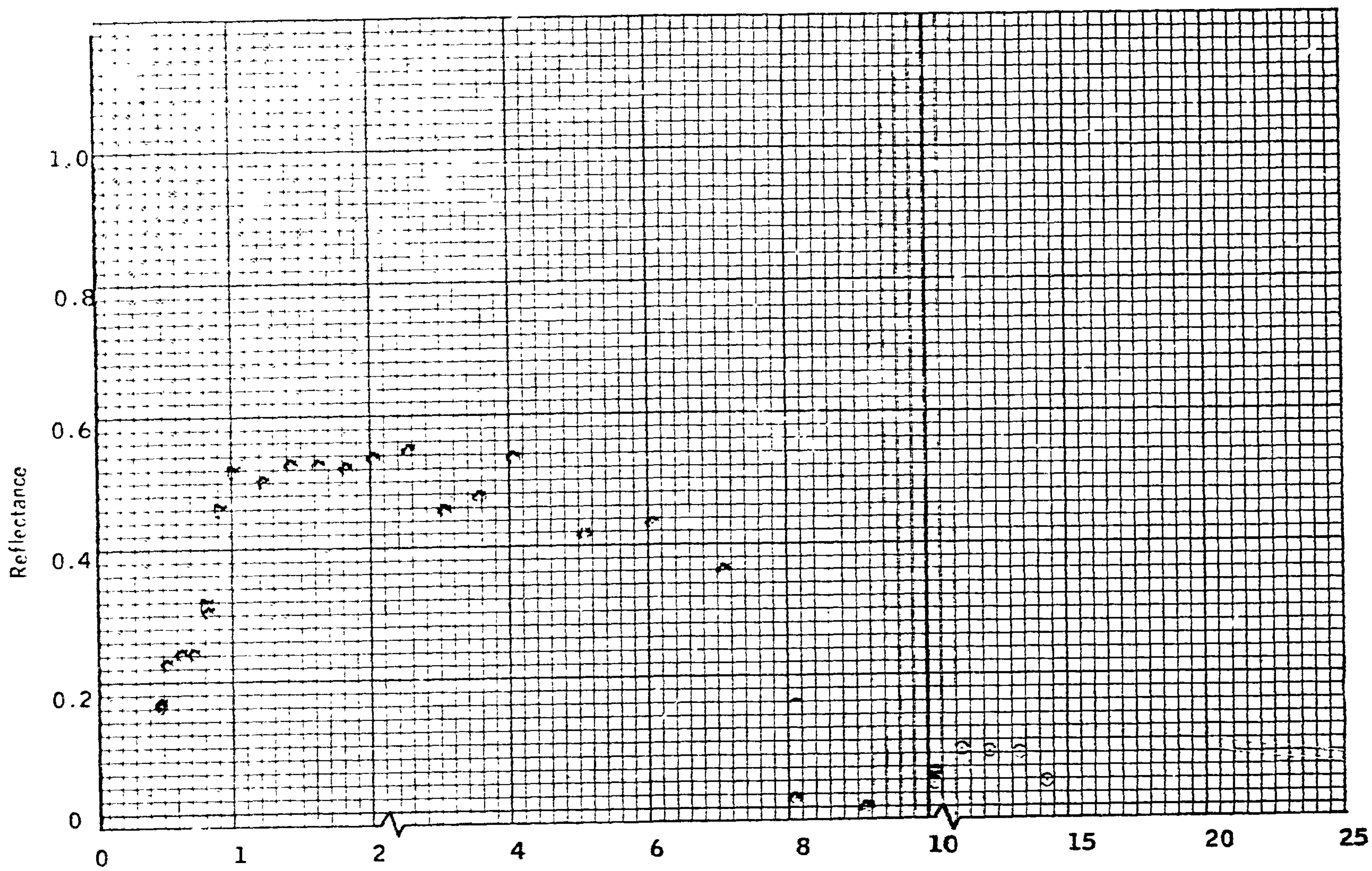


Fig. 118 Normal Spectral Reflectance of Specimen No 35 Temperature RT HT-800F

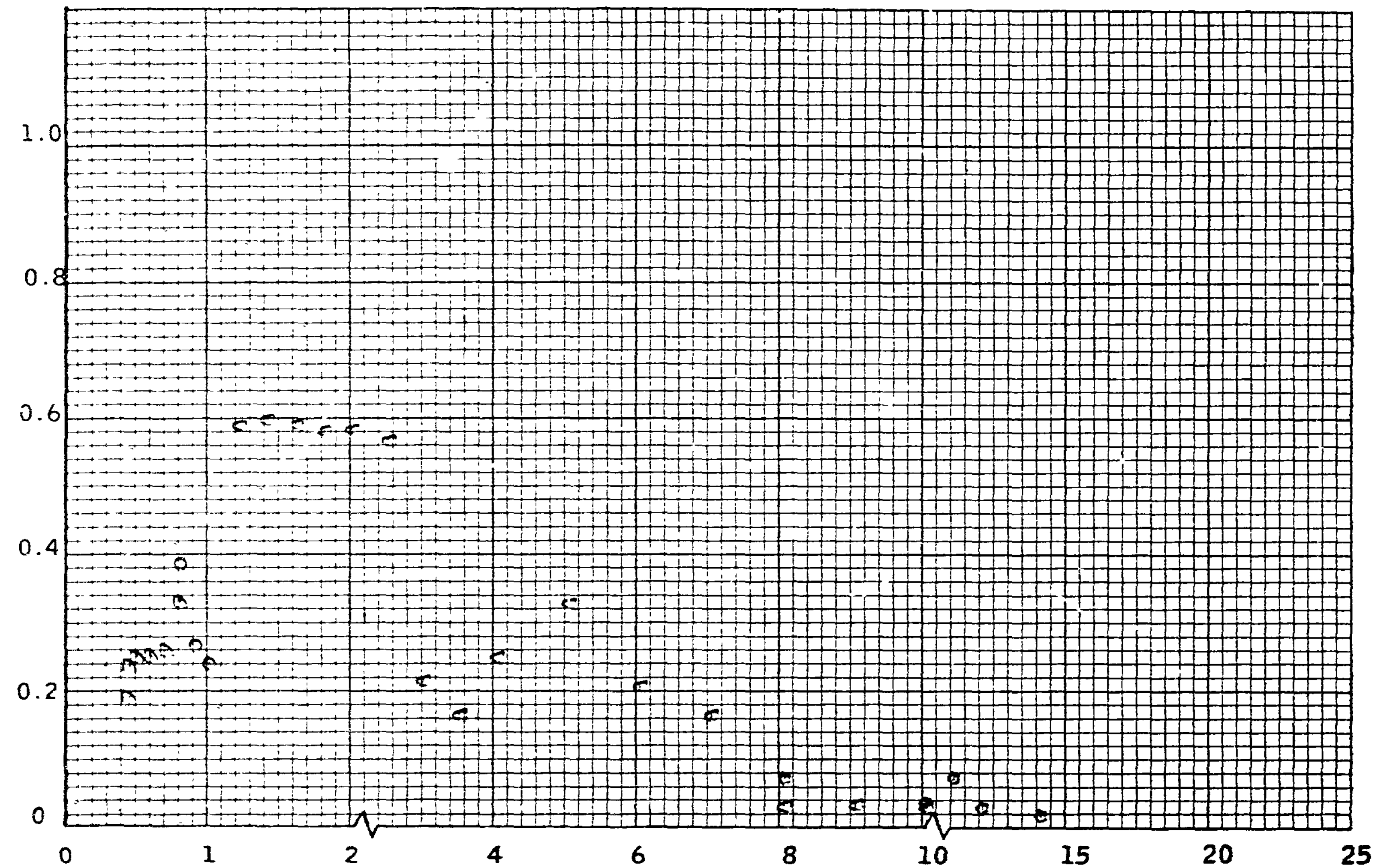


Fig. 119 Normal Spectral Reflectance of Specimen No 35 Temperature RT

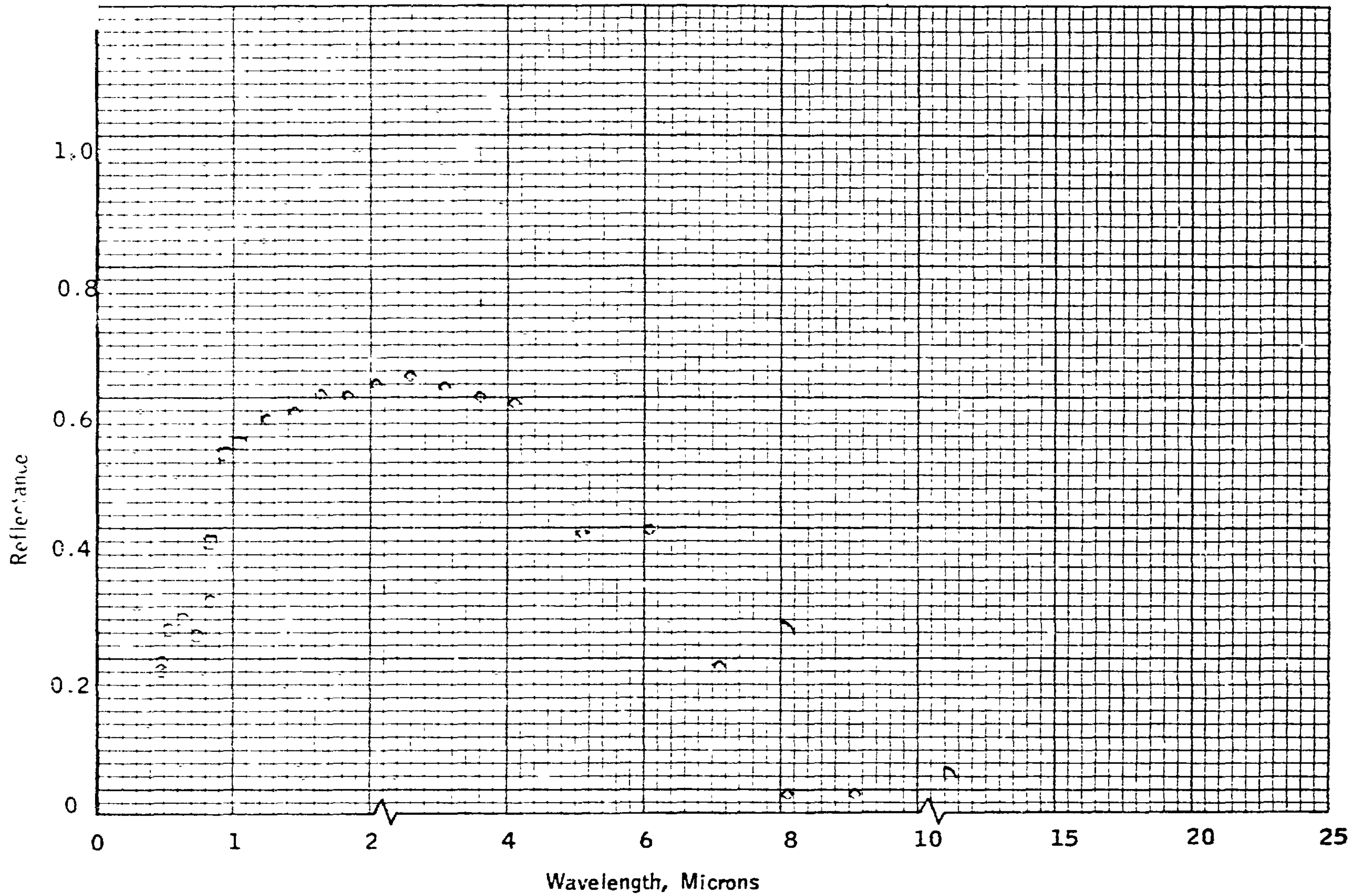


Fig. 120 Normal Spectral Reflectance of Specimen No 35 Temperature 350 F

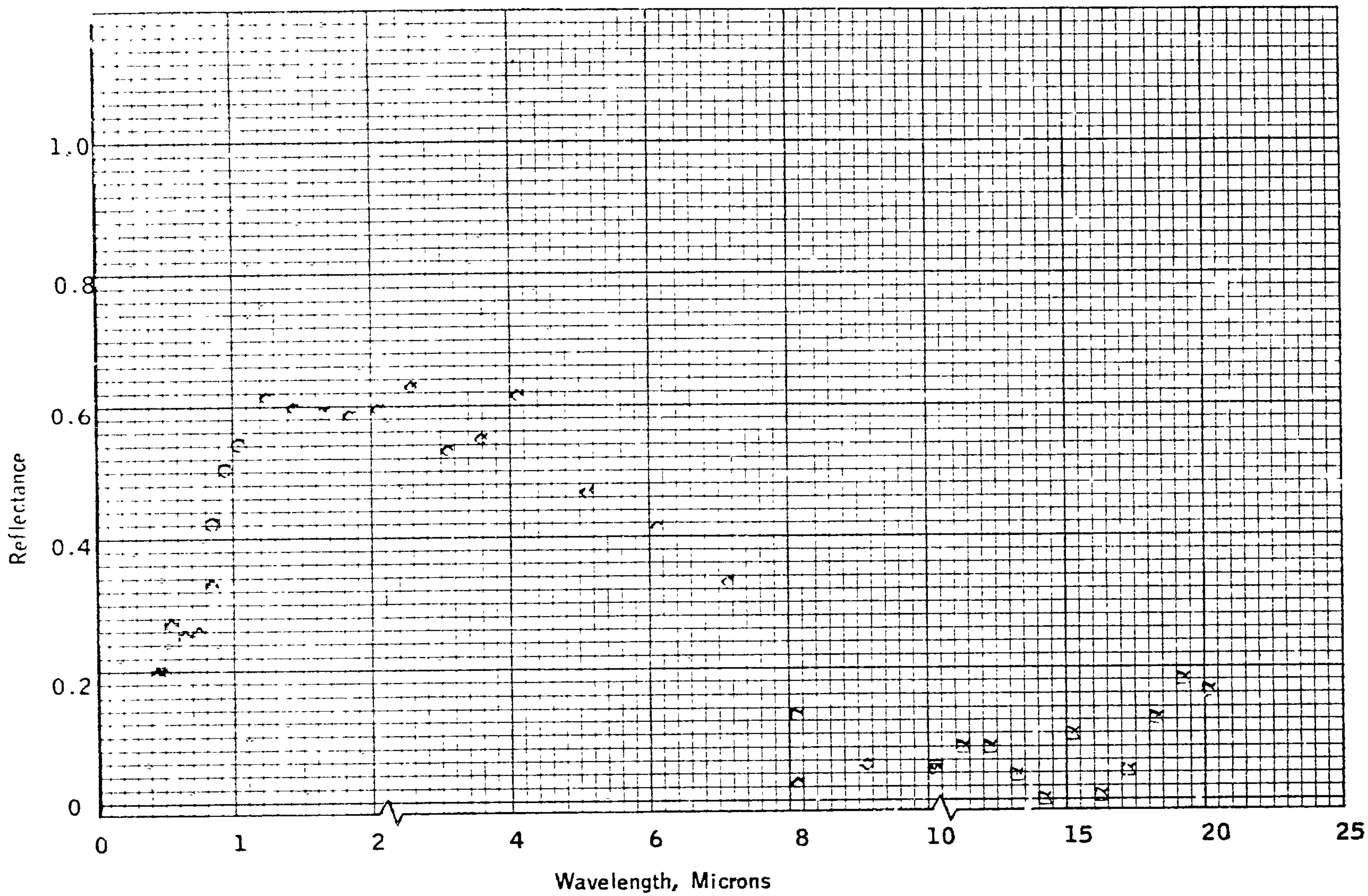


Fig. 121 Normal Spectral Reflectance of Specimen No 35 Temperature RT_f

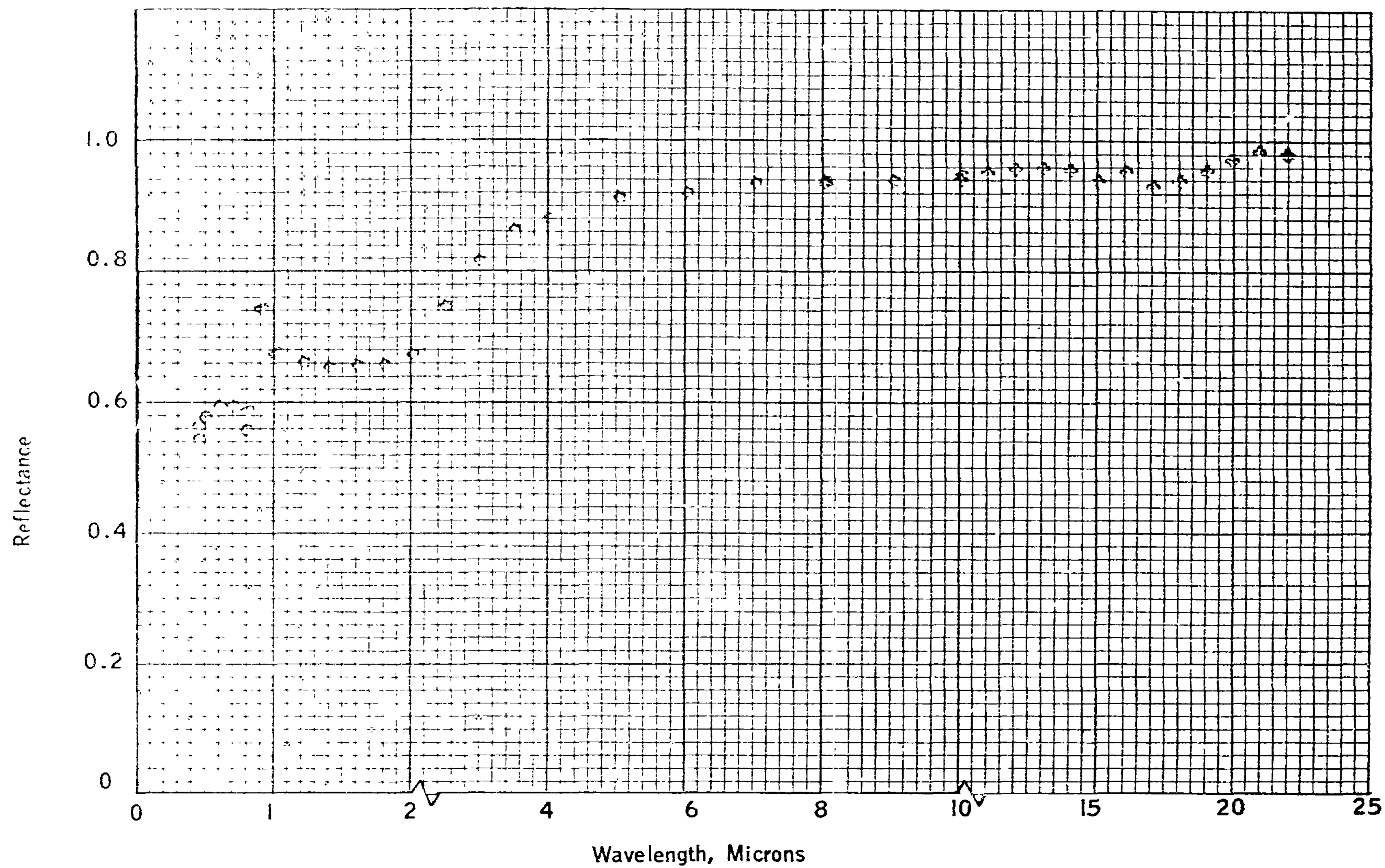


Fig. 122 Normal Spectral Reflectance of Specimen No 152 Temperature RT

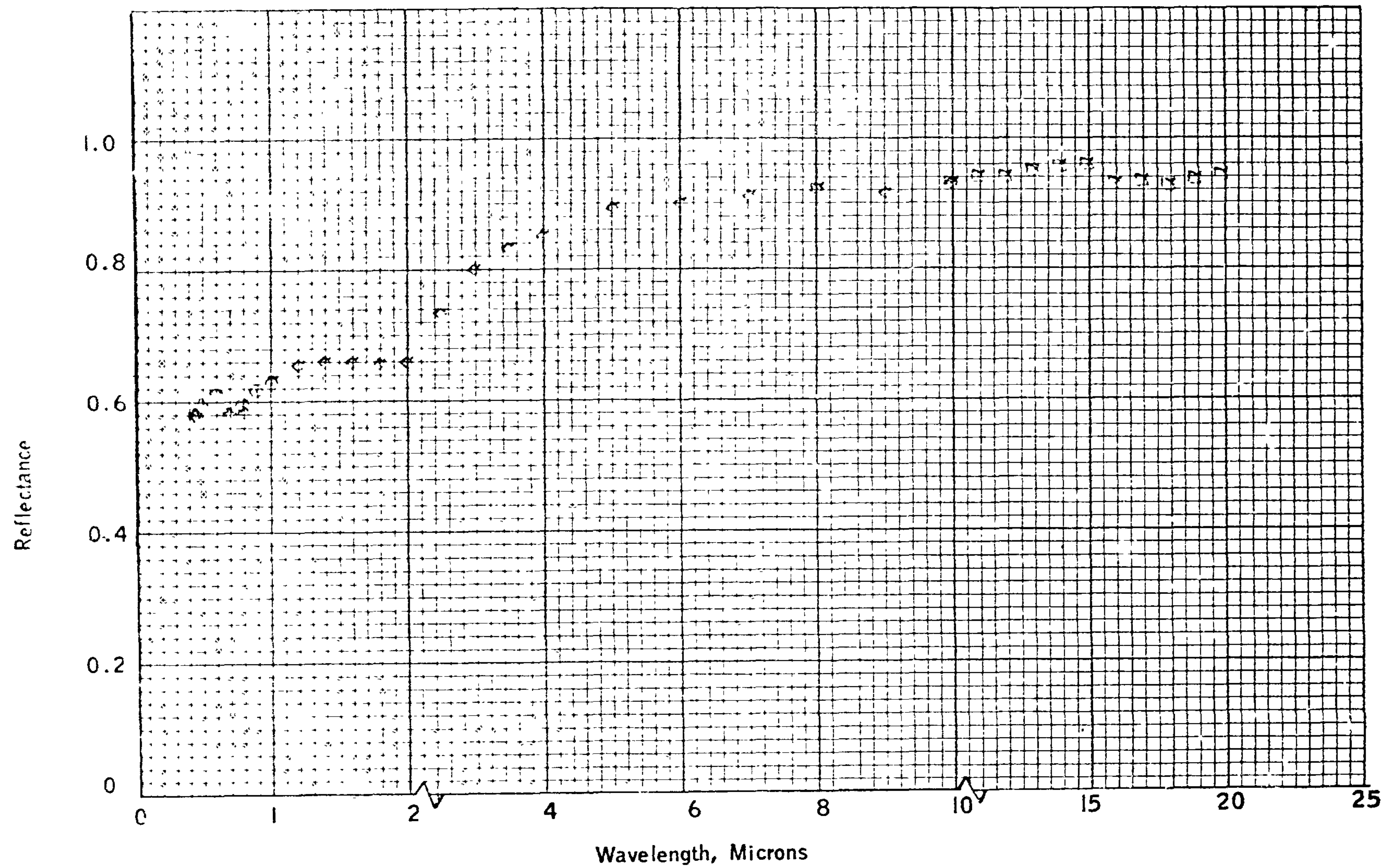


Fig. 123 Normal Spectral Reflectance of Specimen No 152 Temperature RT, MF

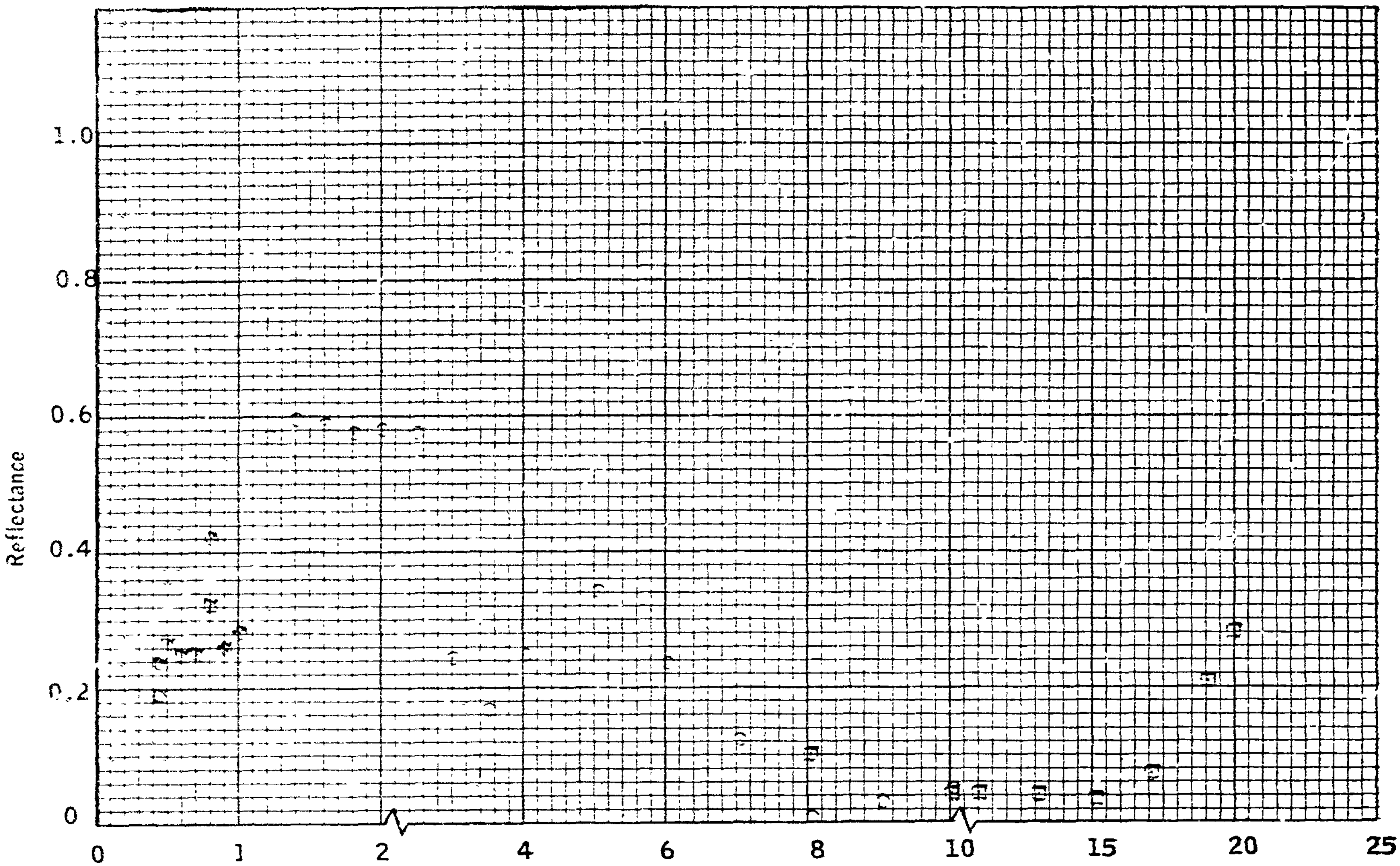


Fig.124 Normal Spectral Reflectance of Specimen No 158 Temperature RT

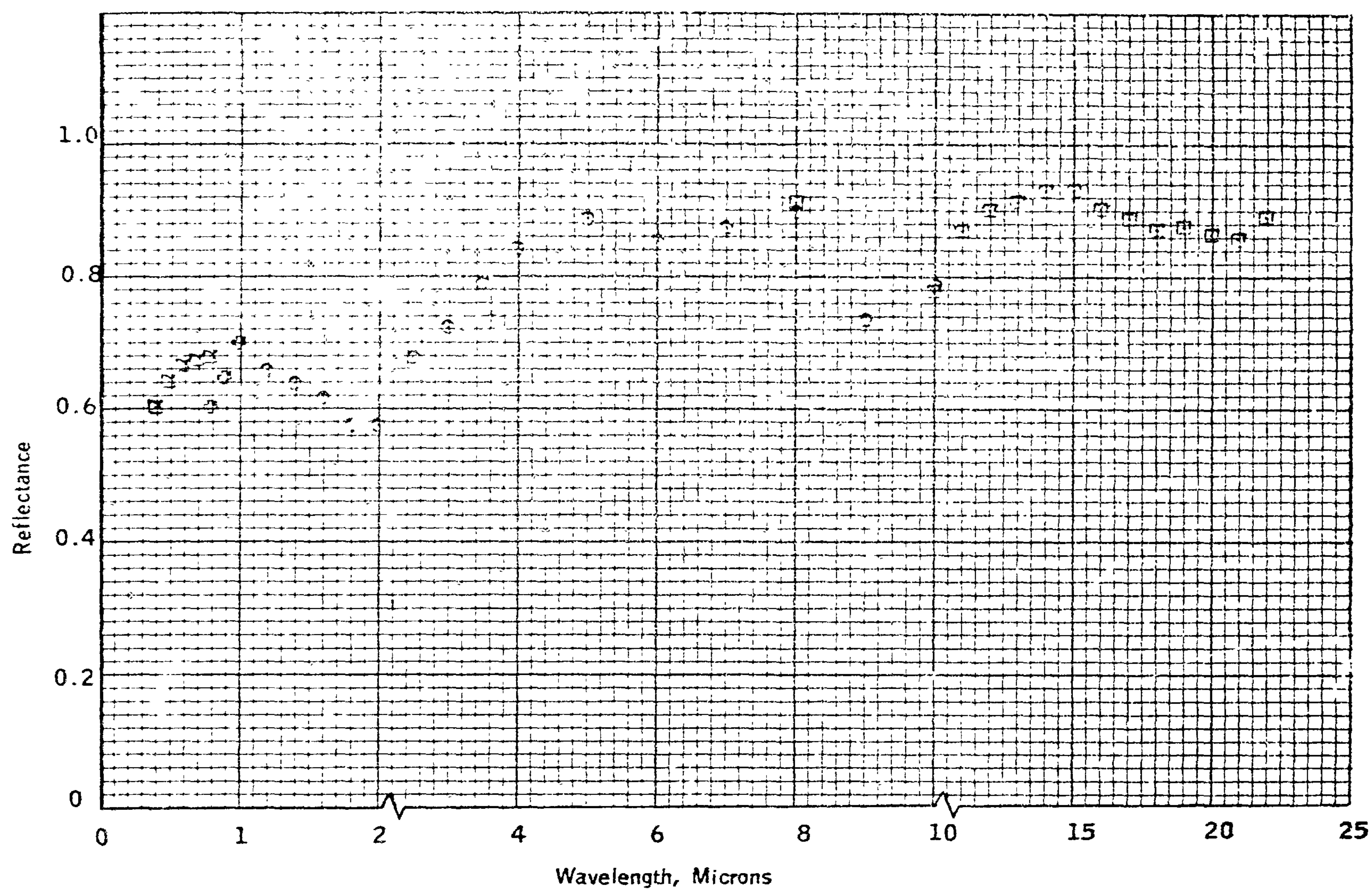


Fig.125 Normal Spectral Reflectance of Specimen No 212 Temperature RT

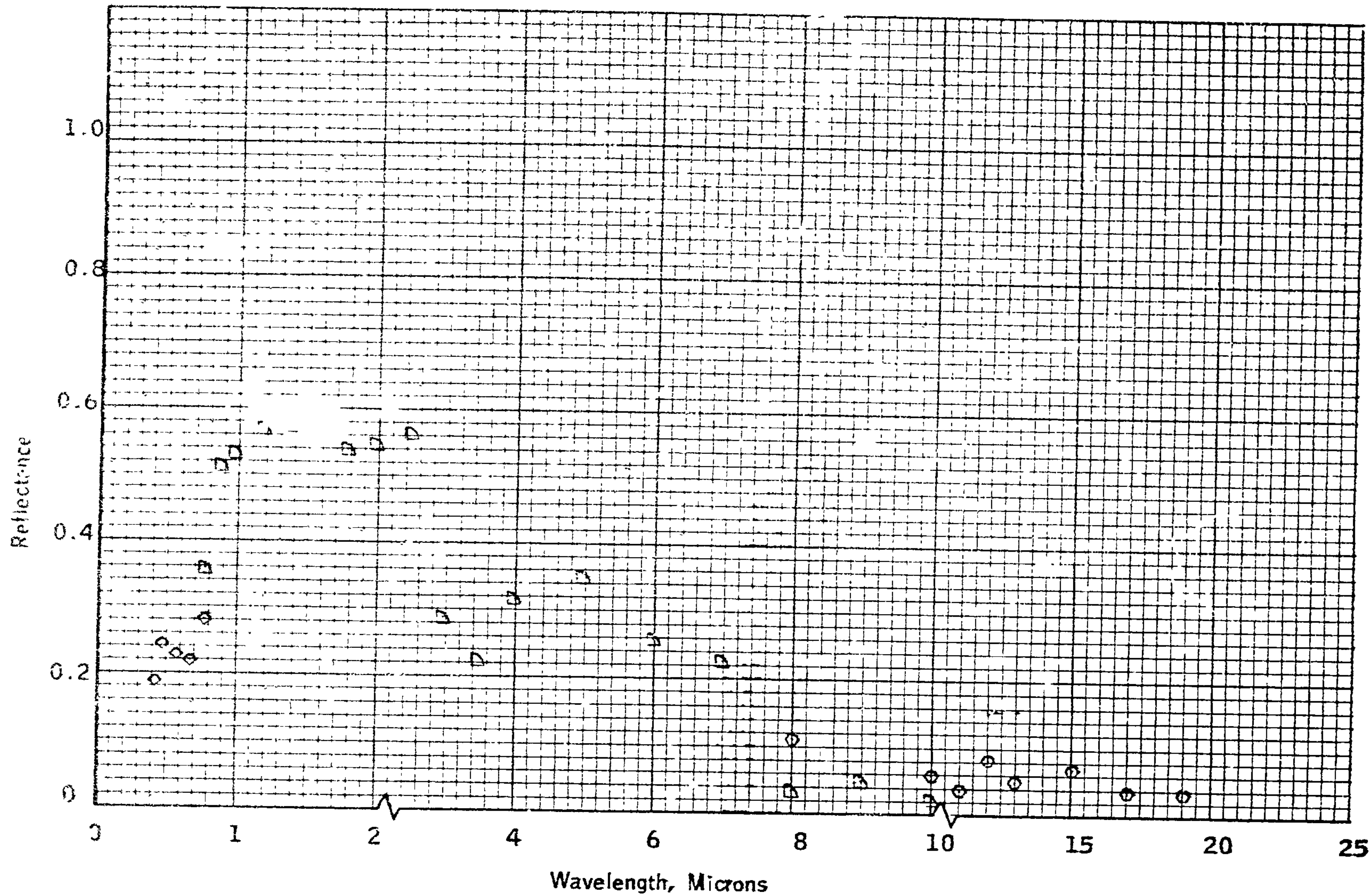


Fig. 126 Normal Spectral Reflectance of Specimen No 213 Temperature RT

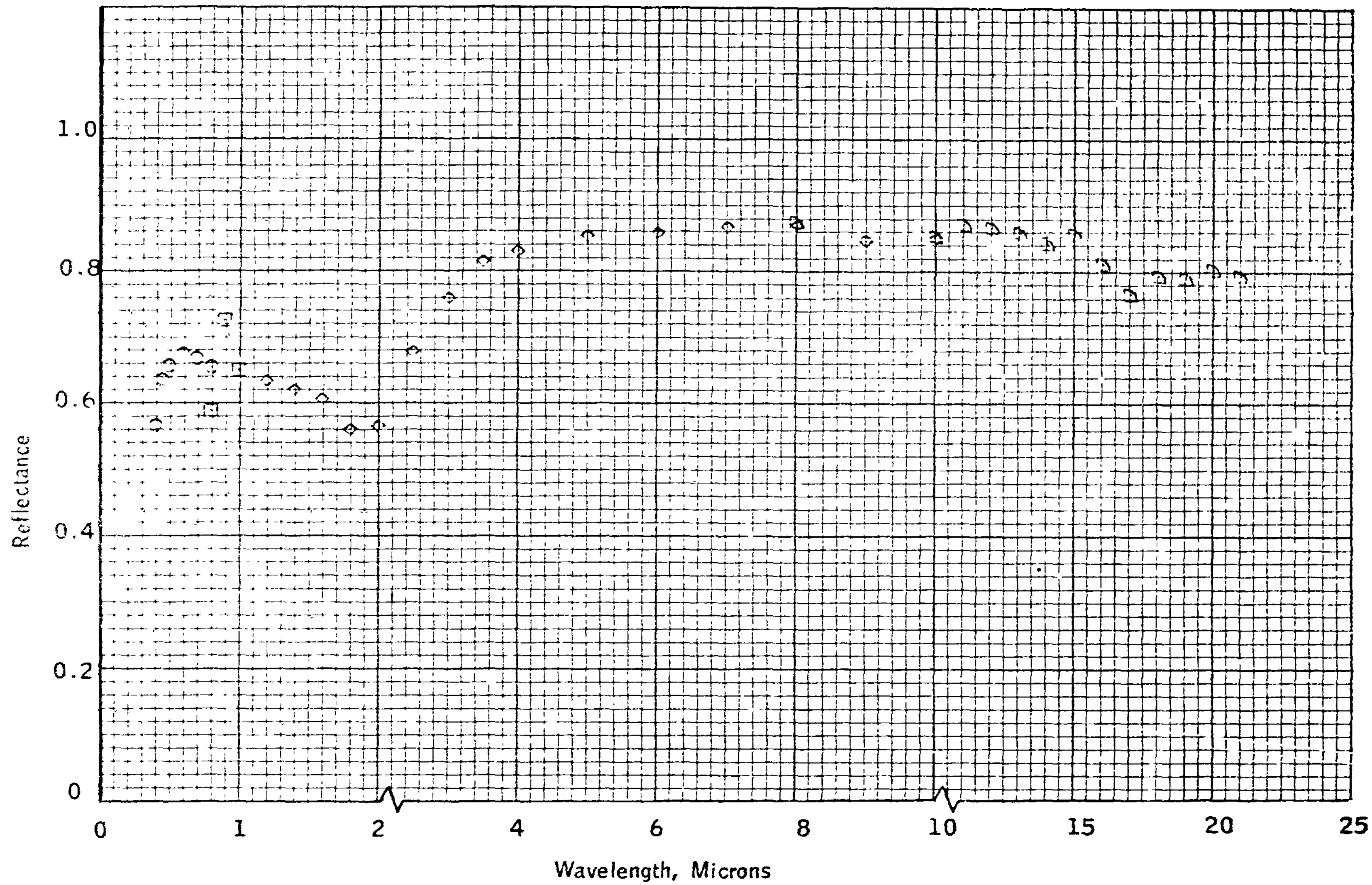


Fig. 127 Normal Spectral Reflectance of Specimen No 214 Temperature RT

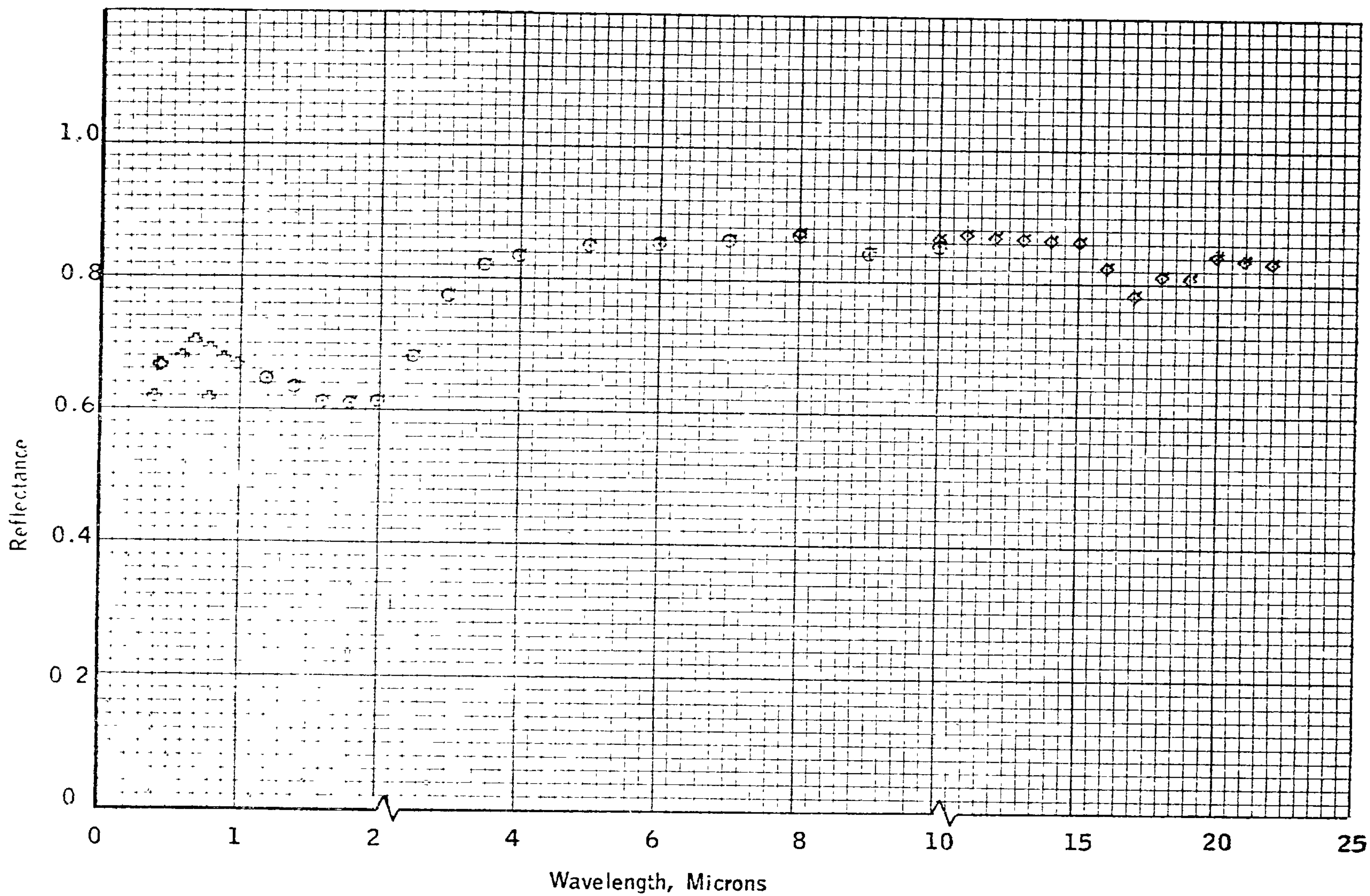


Fig. 128 Normal Spectral Reflectance of Specimen No 214 Temperature 3 50 F

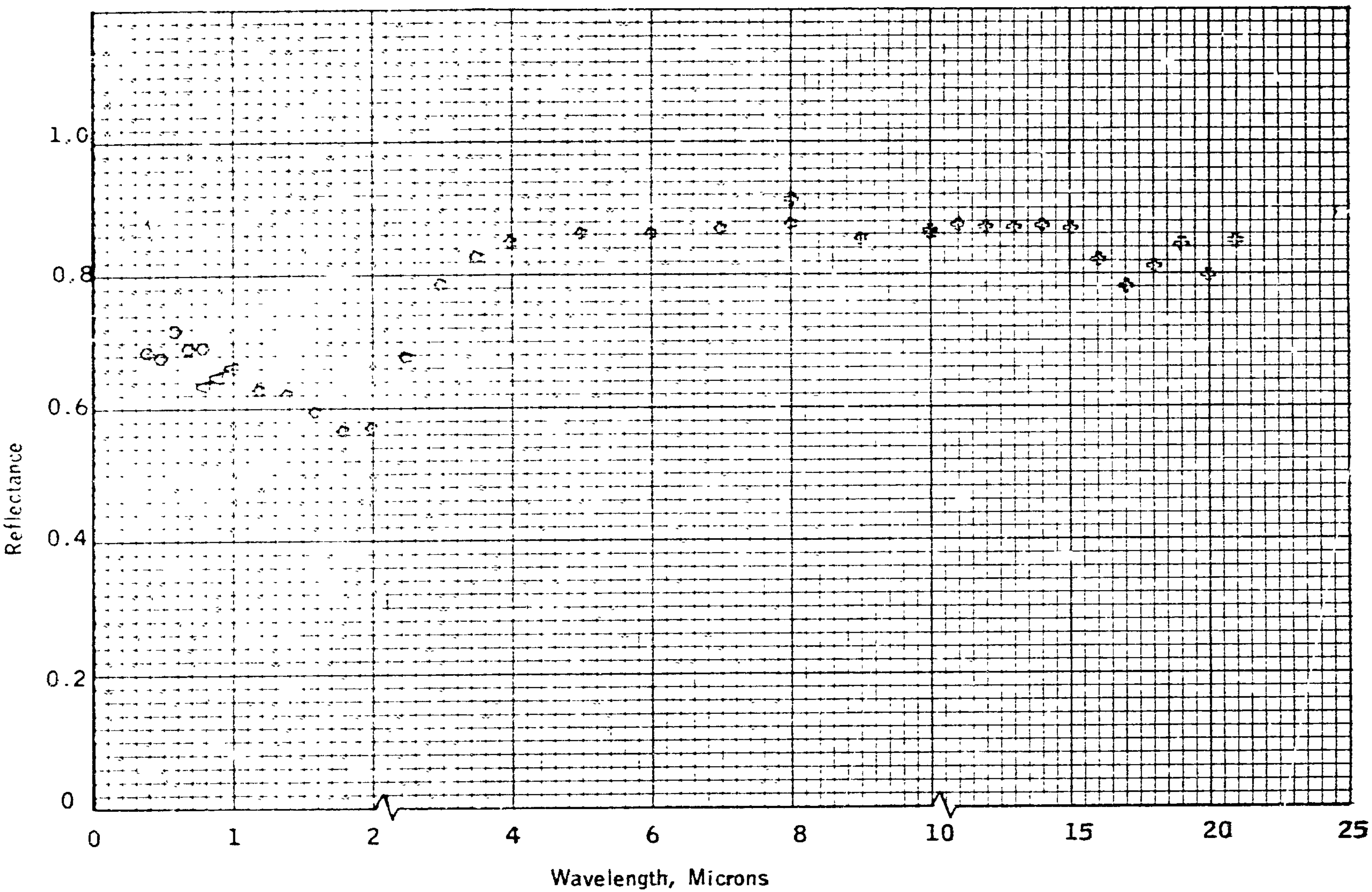


Fig. 129 Normal Spectral Reflectance of Specimen No 214 Temperature RT_f

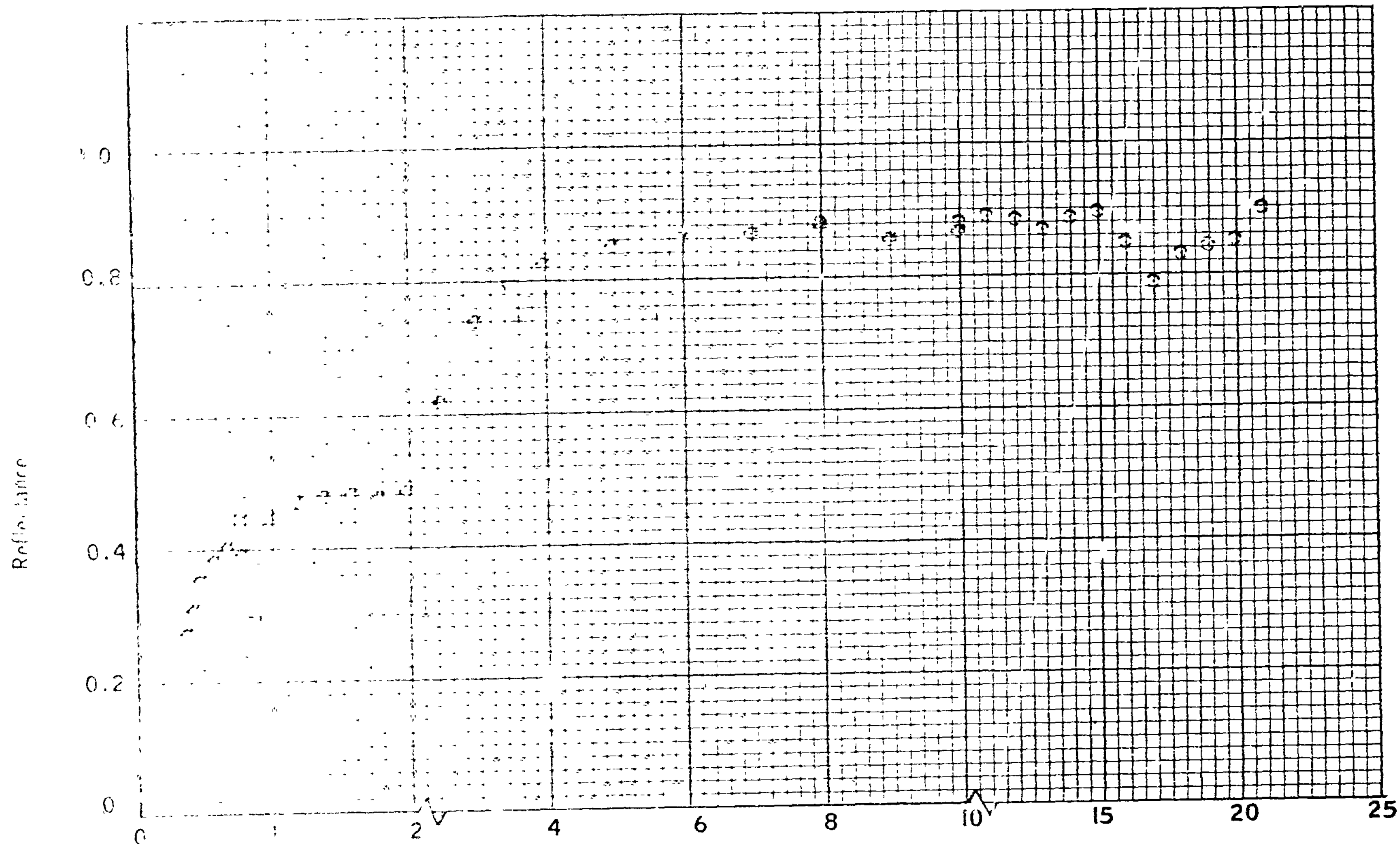


Fig. 130 Normal Spectral Reflectance of Specimen No 214 Temperature RT, HT-800 F

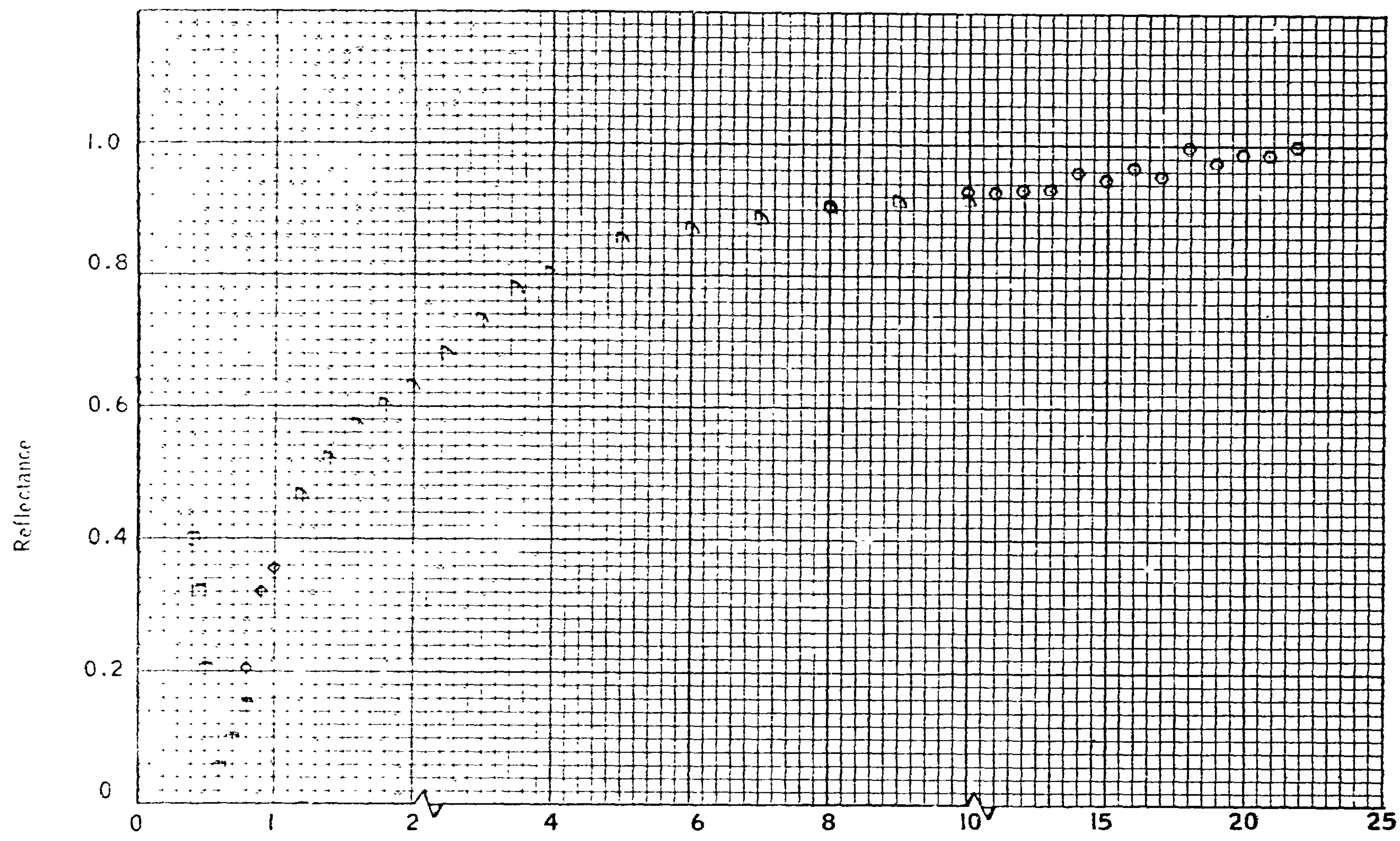


Fig. 131 Normal Spectral Reflectance of Specimen No 38 Temperature RT

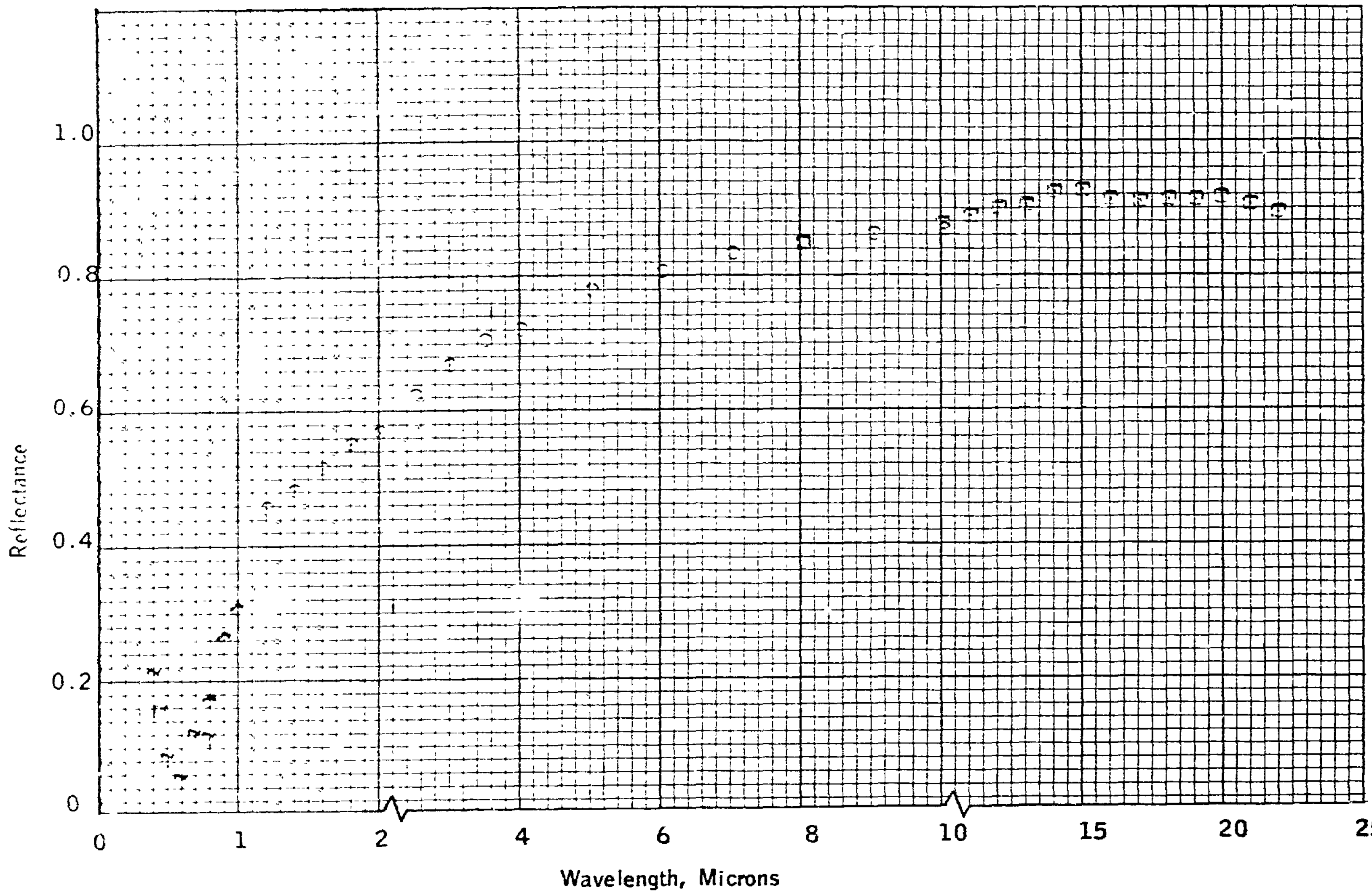


Fig. 132 Normal Spectral Reflectance of Specimen No 43 Temperature RT

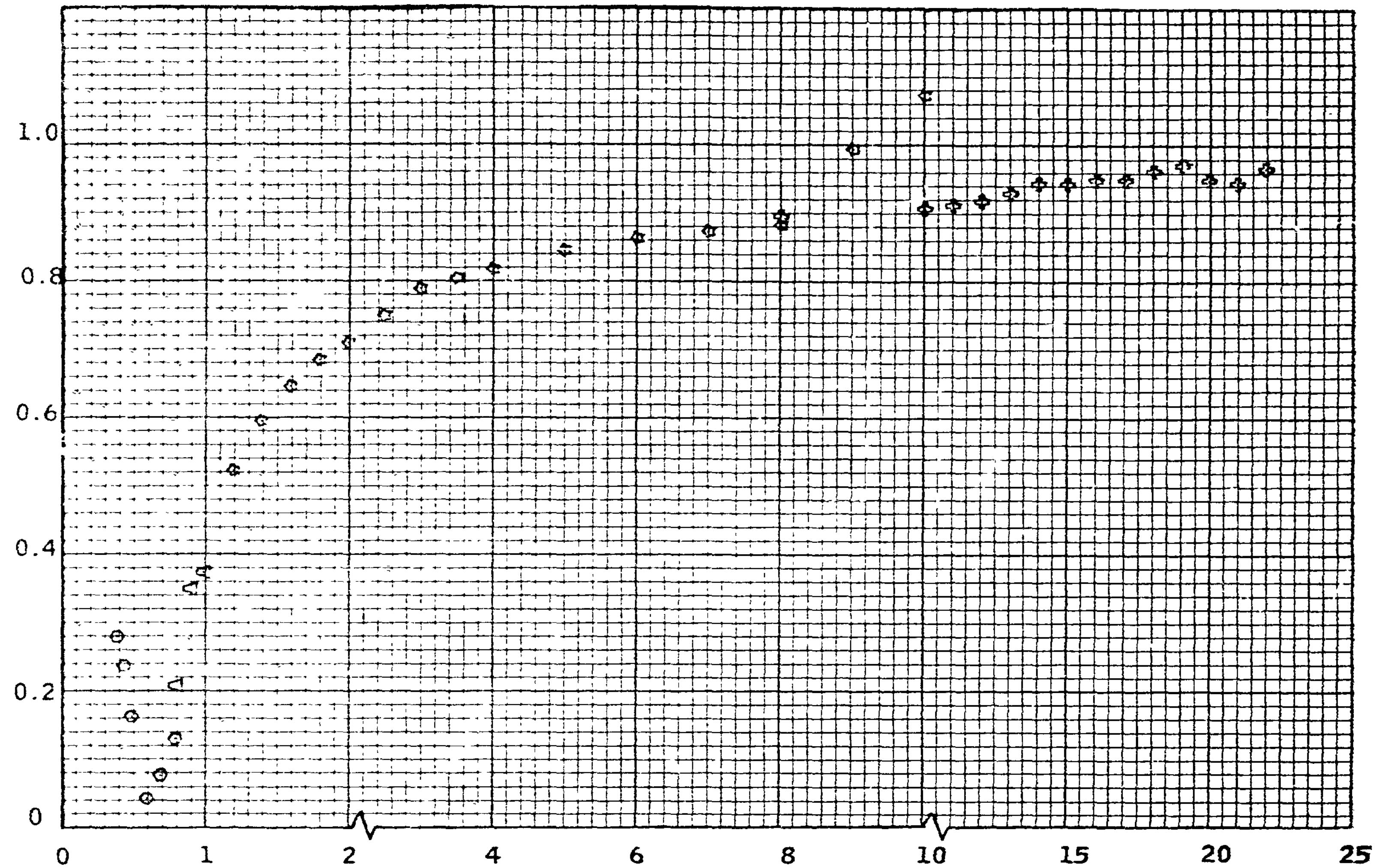


Fig. 133 Normal Spectral Reflectance of Specimen No 203 Temperature RT

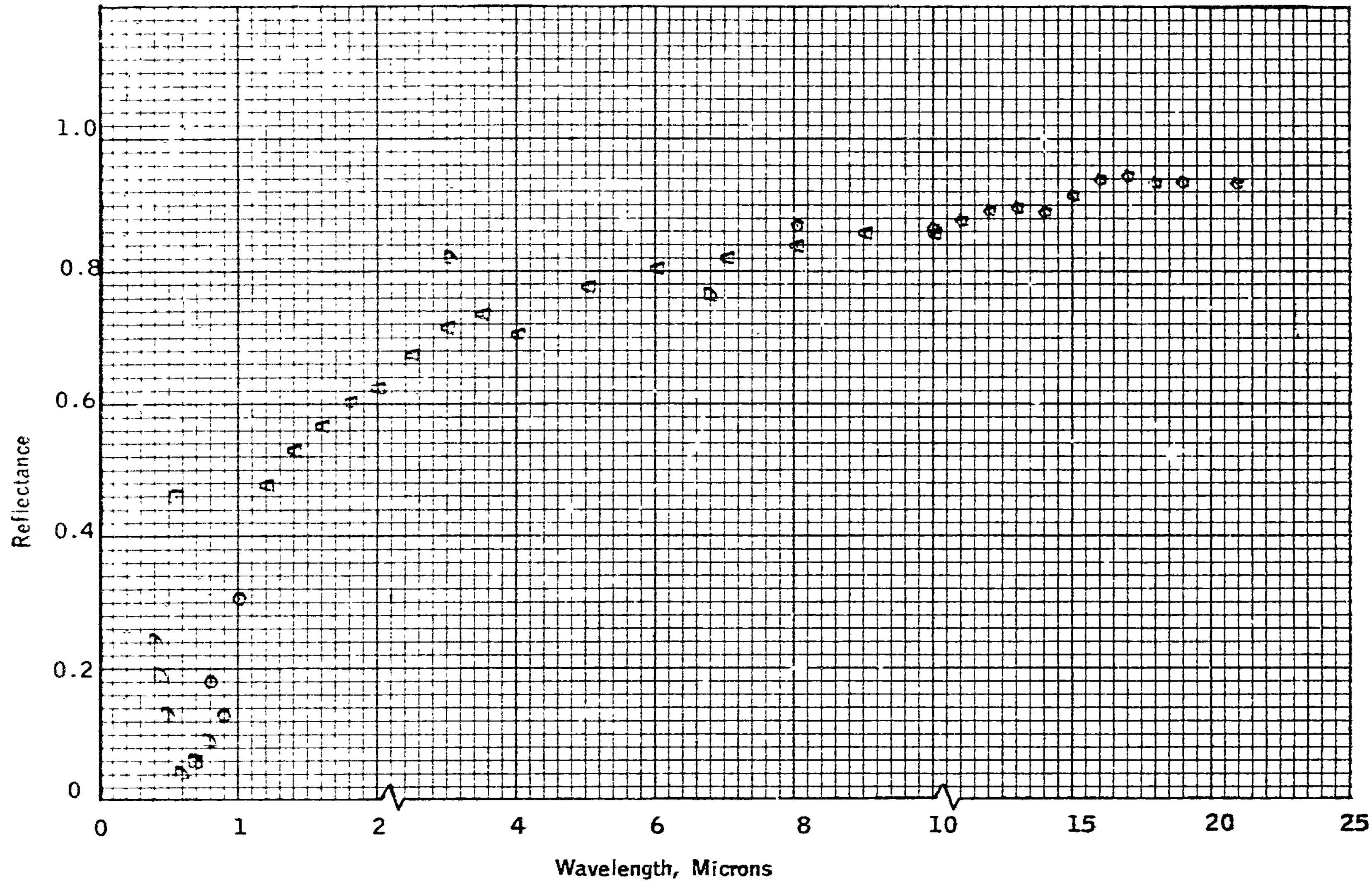


Fig. 134 Normal Spectral Reflectance of Specimen No 207 Temperature RT

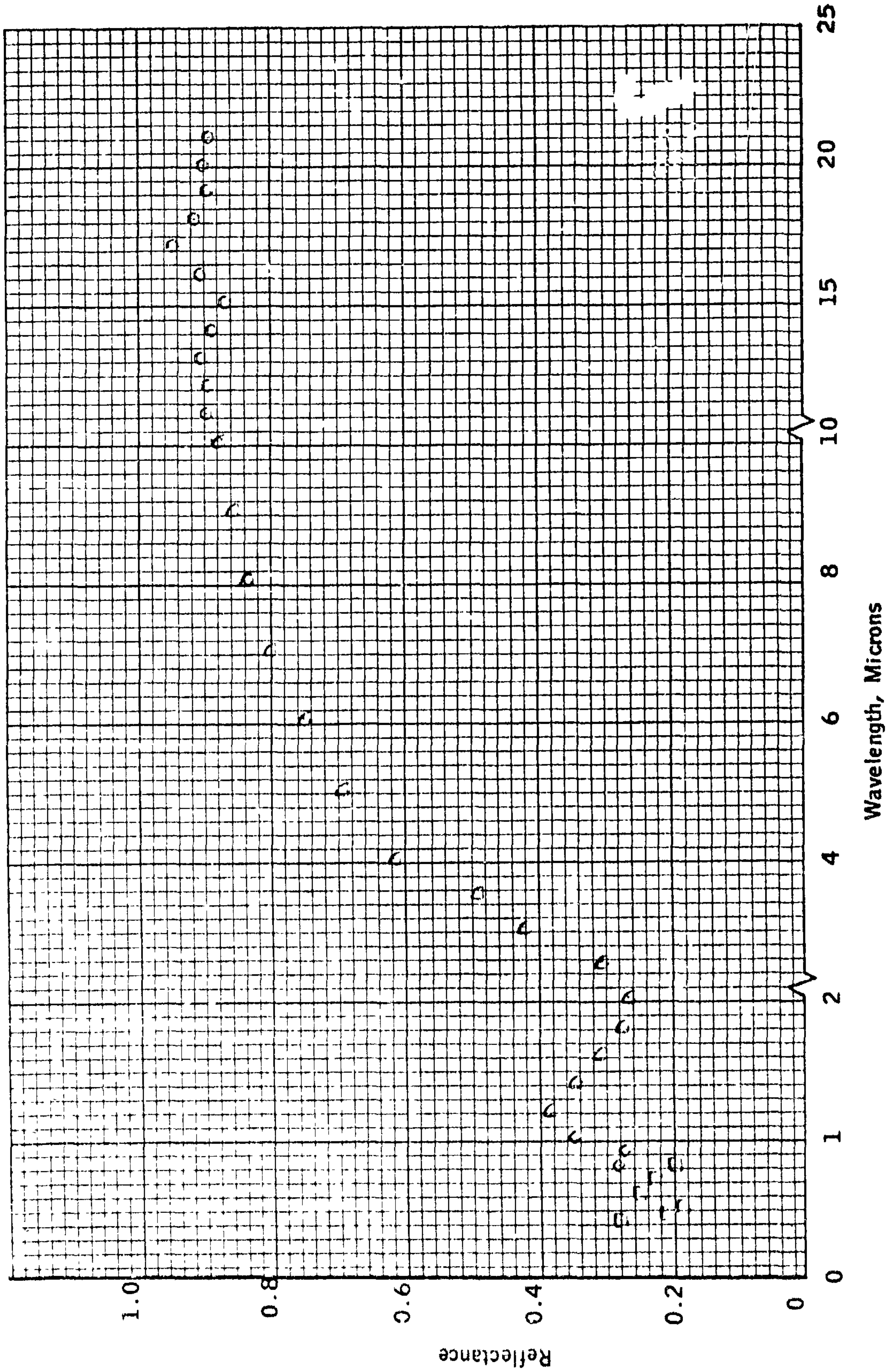


Fig.135 Normal Spectral Reflectance of Specimen No 45 Temperature RT

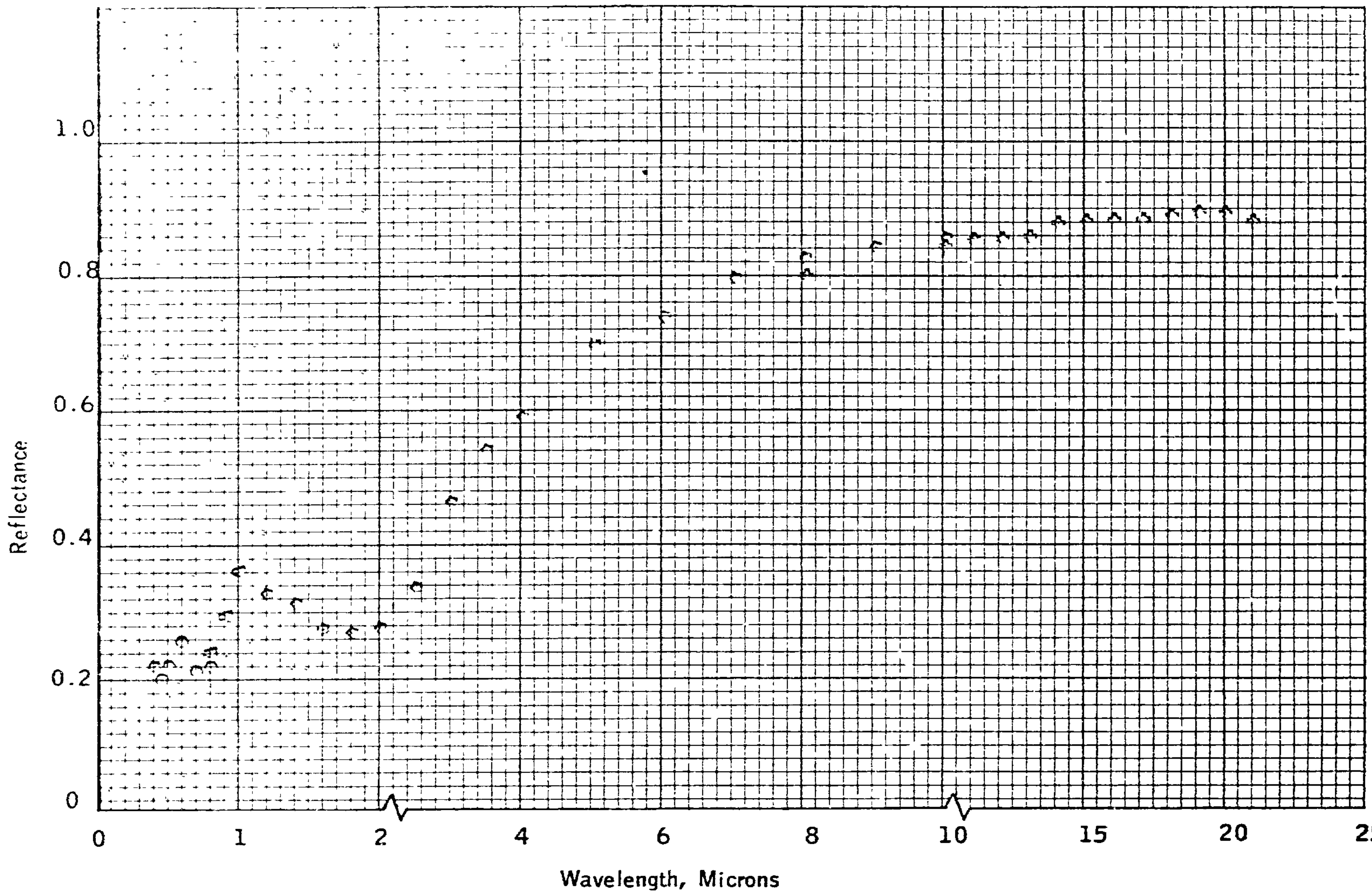


Fig. 136 Normal Spectral Reflectance of Specimen No 45 Temperature 300 F

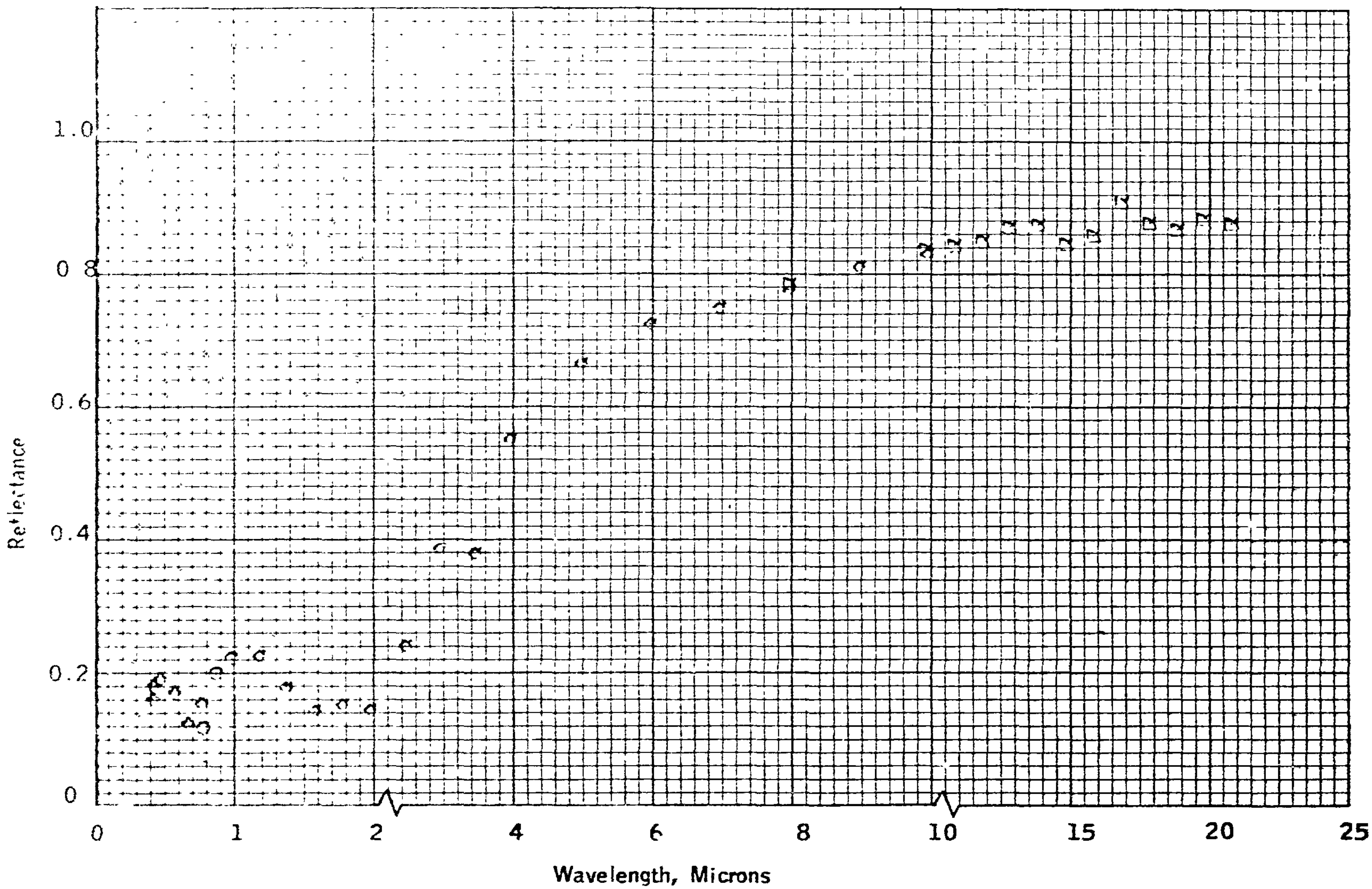


Fig. 137 Normal Spectral Reflectance of Specimen No45 Temperature 600 F

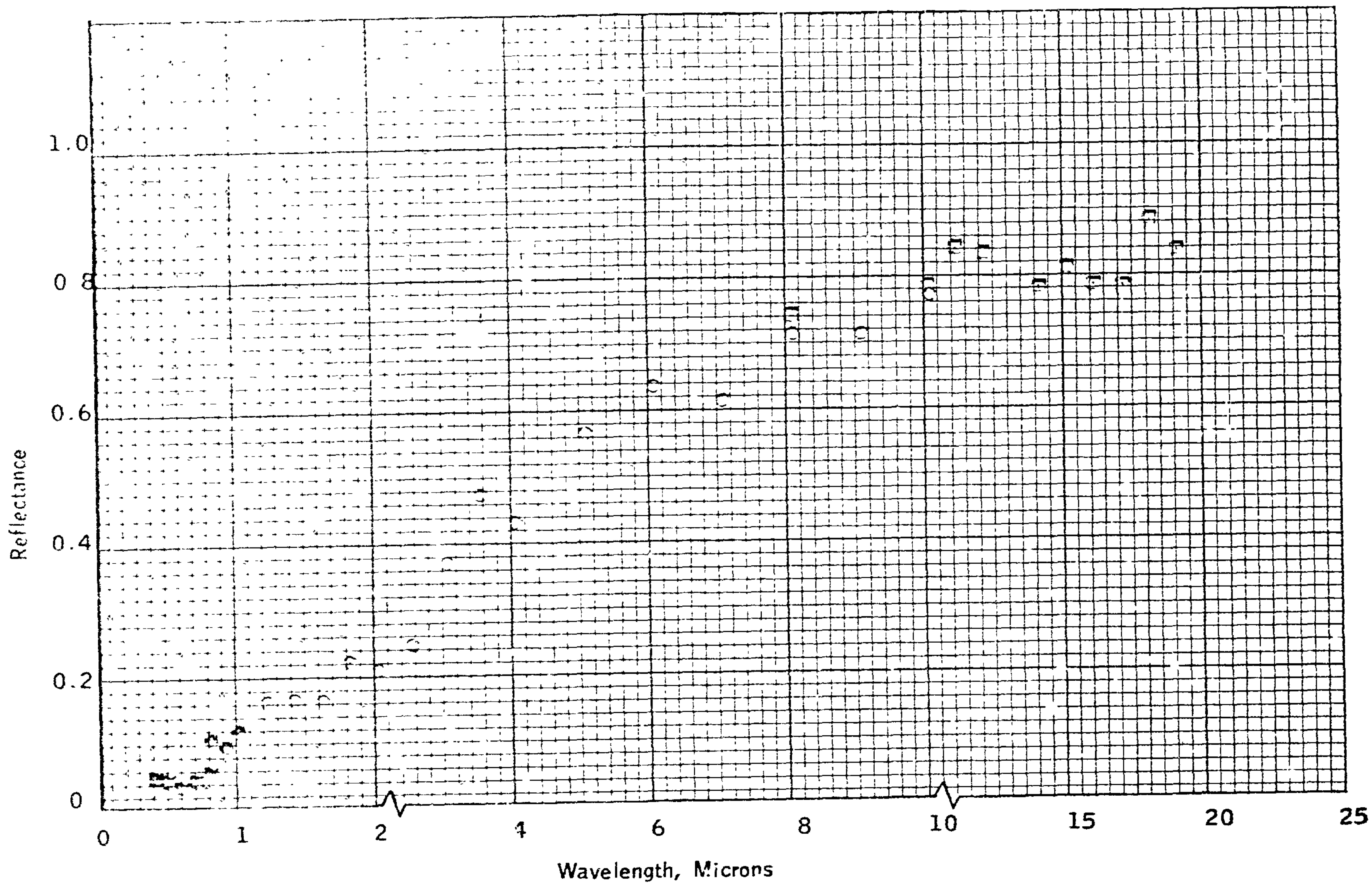


Fig. 138 Normal Spectral Reflectance of Specimen No 45 Temperature 900F

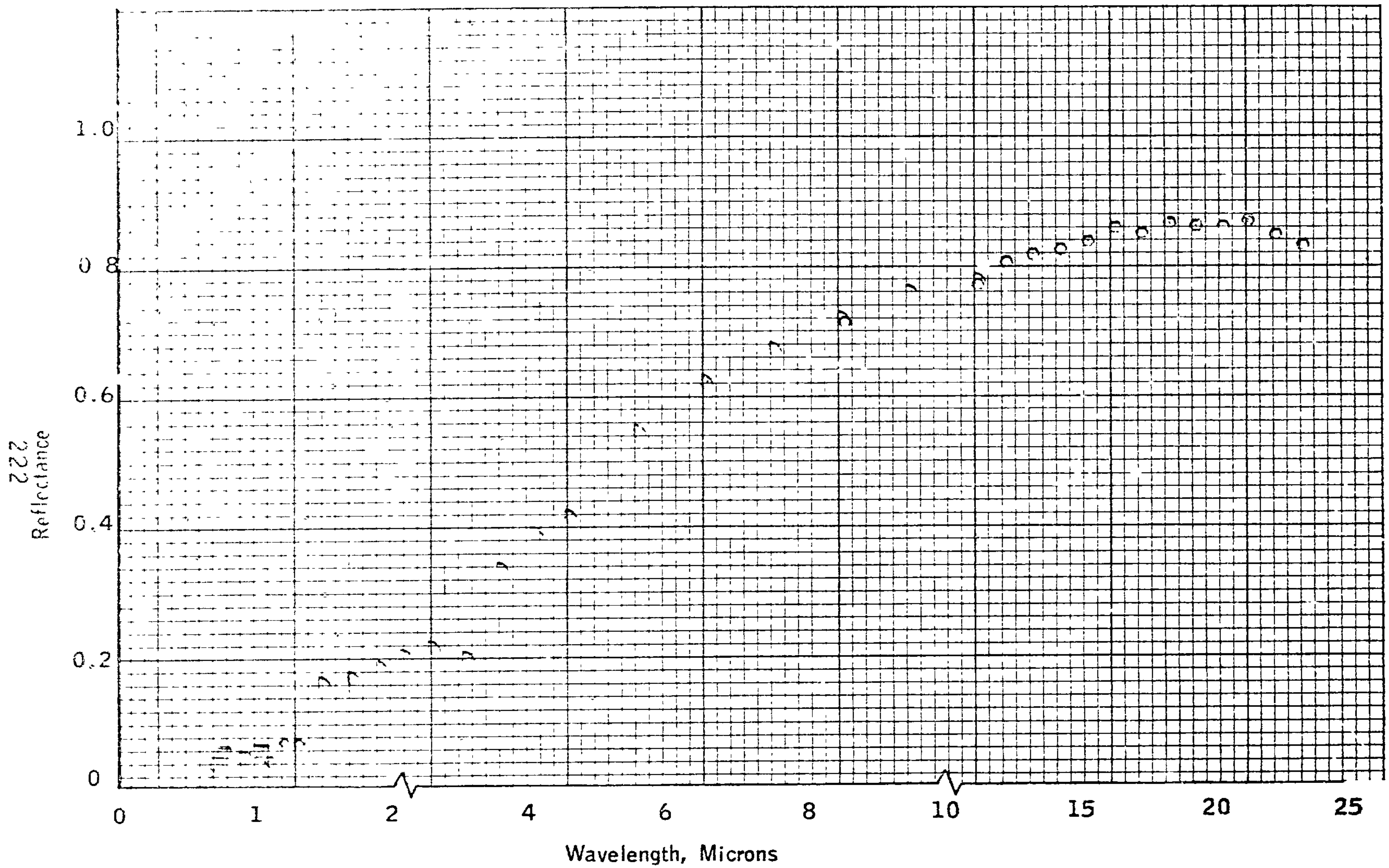


Fig. 139 Normal Spectral Reflectance of Specimen No 45 Temperature RT_f

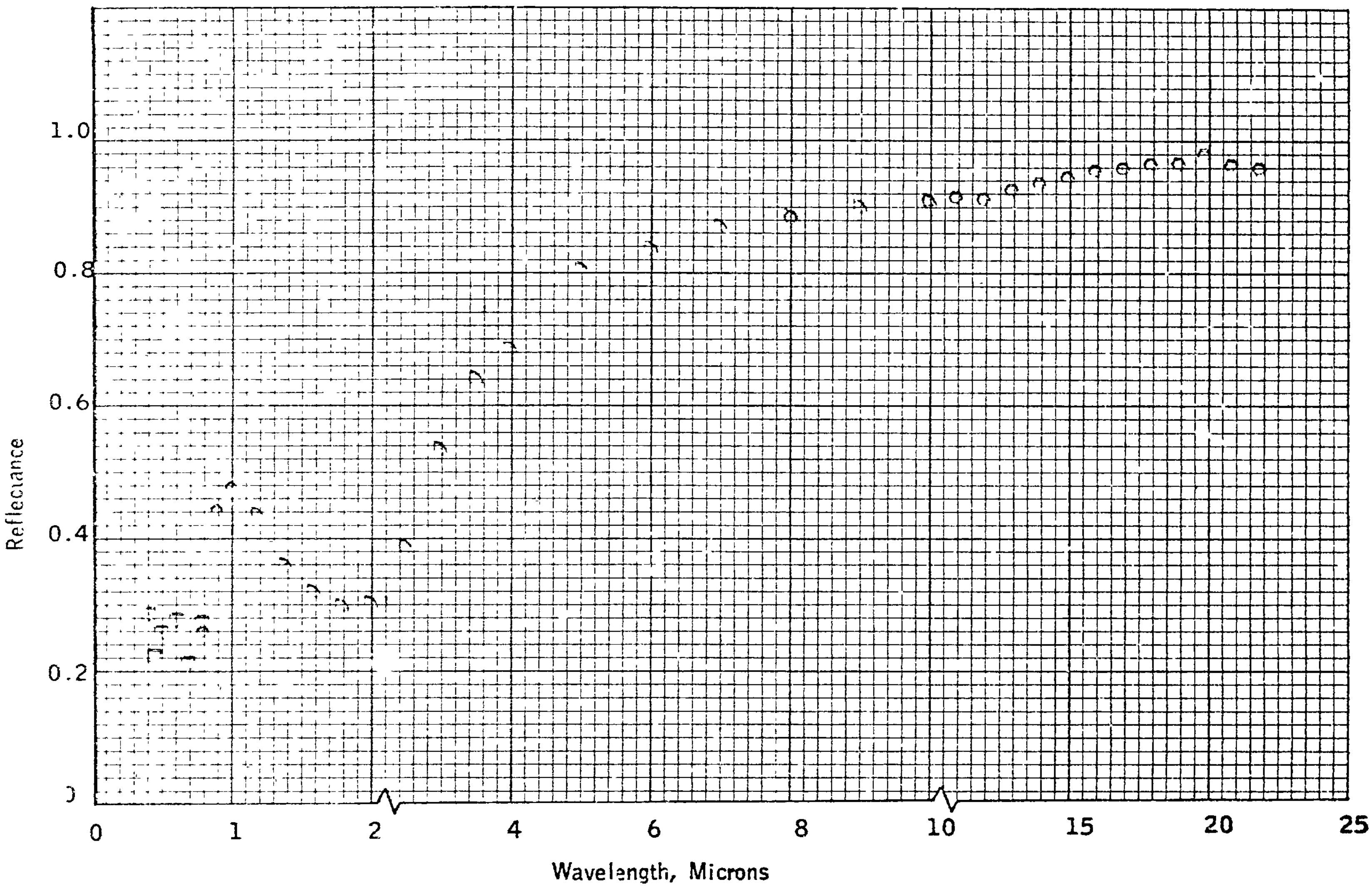


Fig. 140 Normal Spectral Reflectance of Specimen No 48 Temperature RT

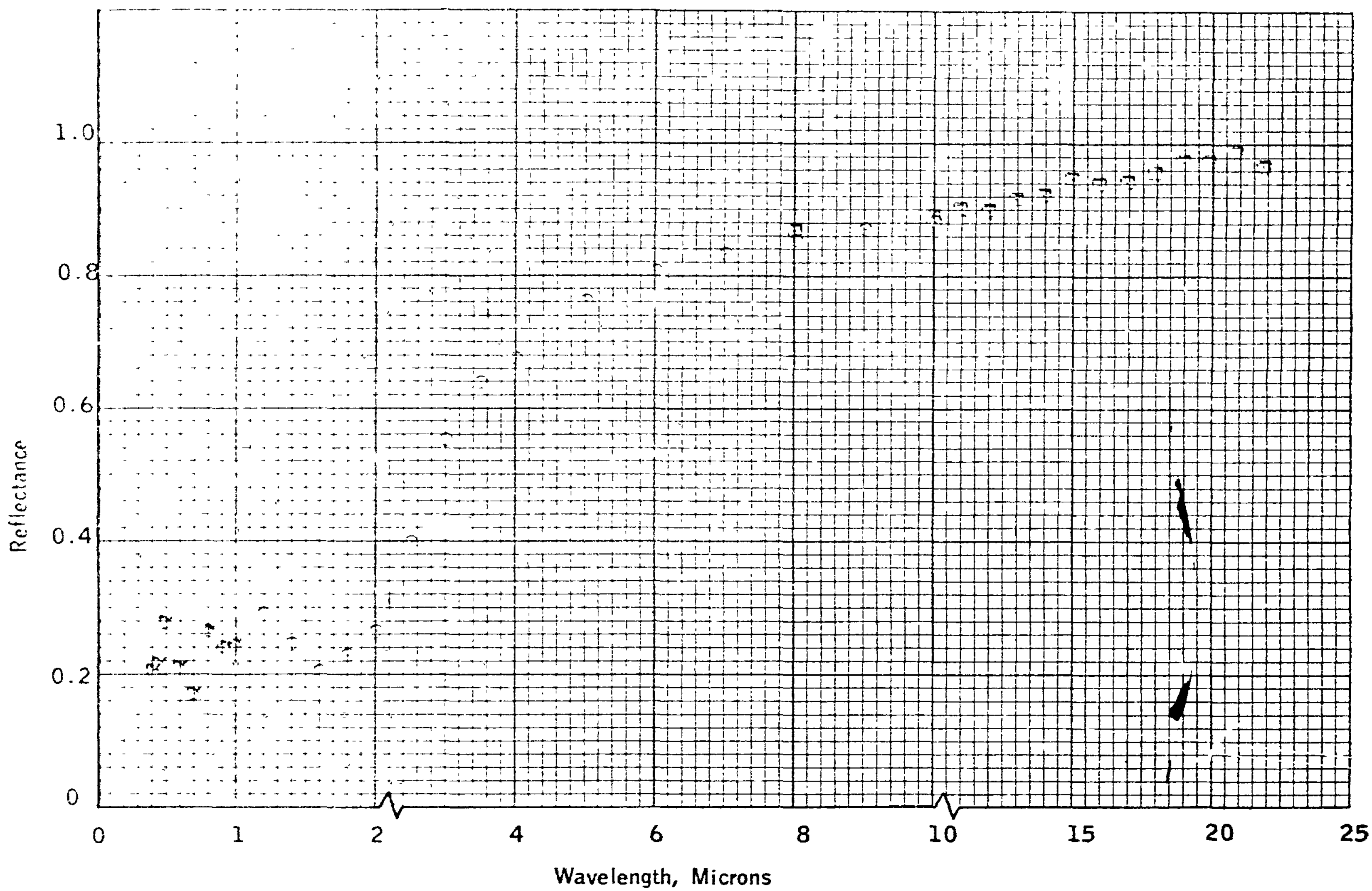


Fig. 141 Normal Spectral Reflectance of Specimen No 48 Temperature 500F

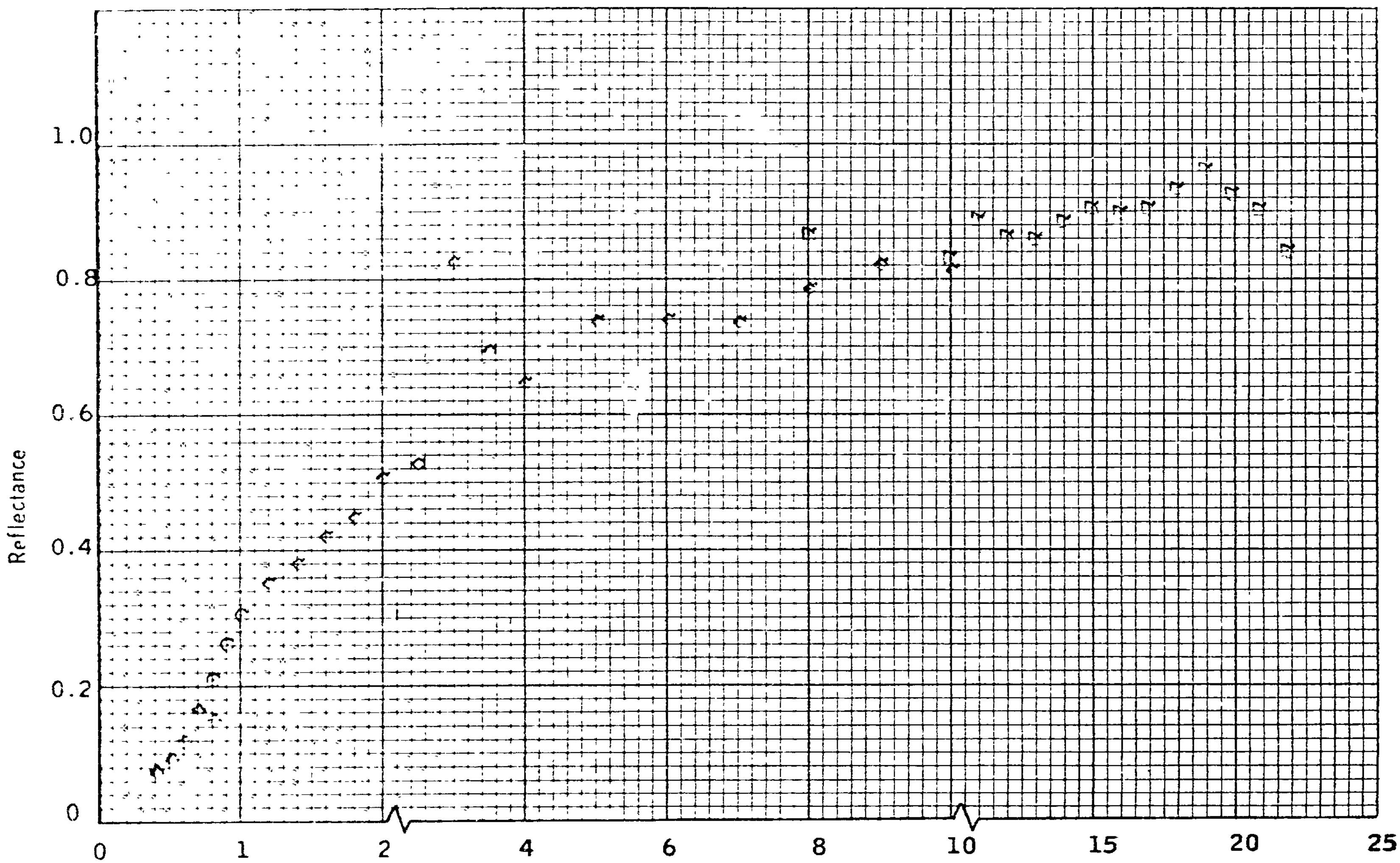


Fig. 142 Normal Spectral Reflectance of Specimen No 48 Temperature 1000F

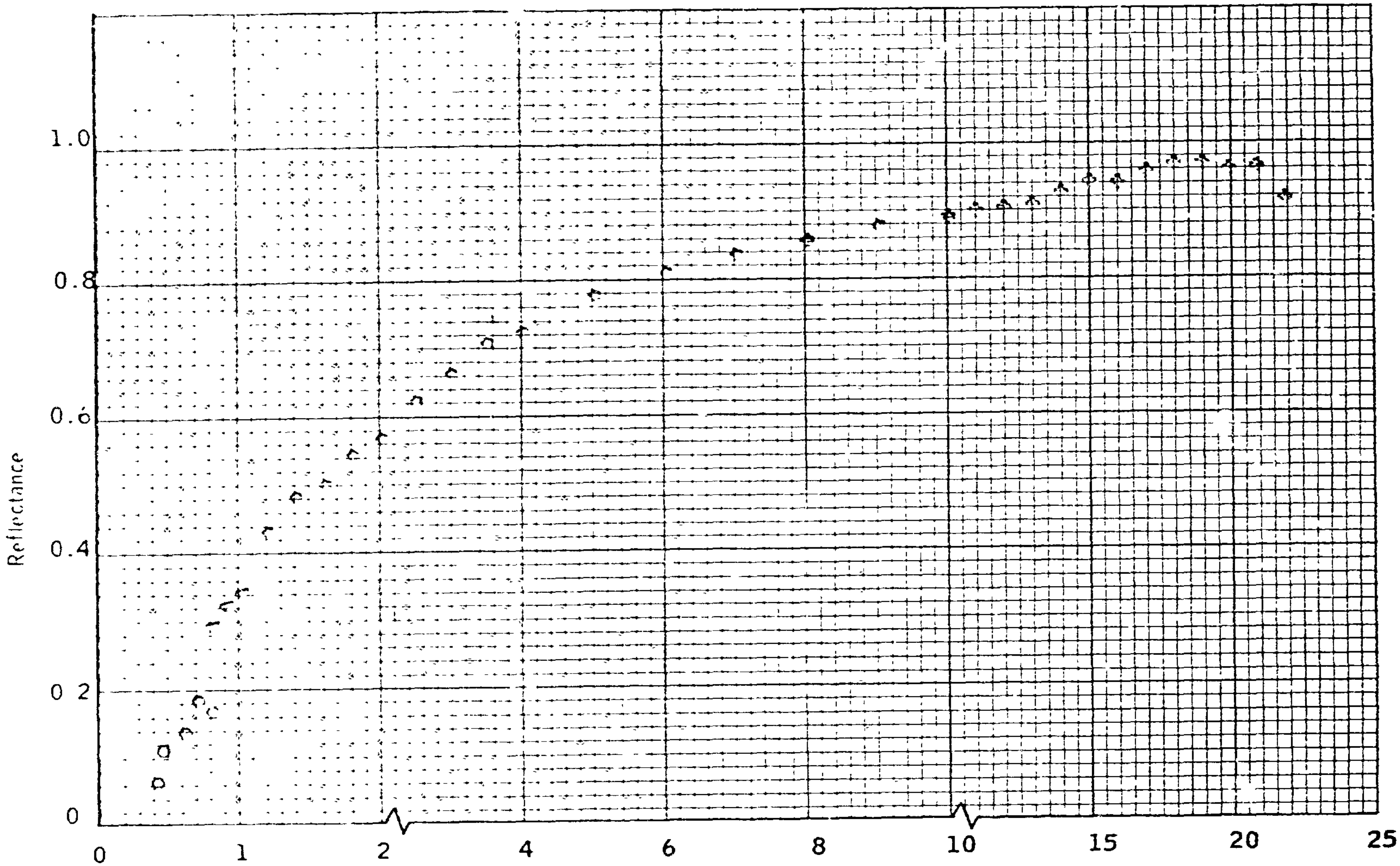


Fig 143 Normal Spectral Reflectance of Specimen No 48 Temperature RT_f (1000F)

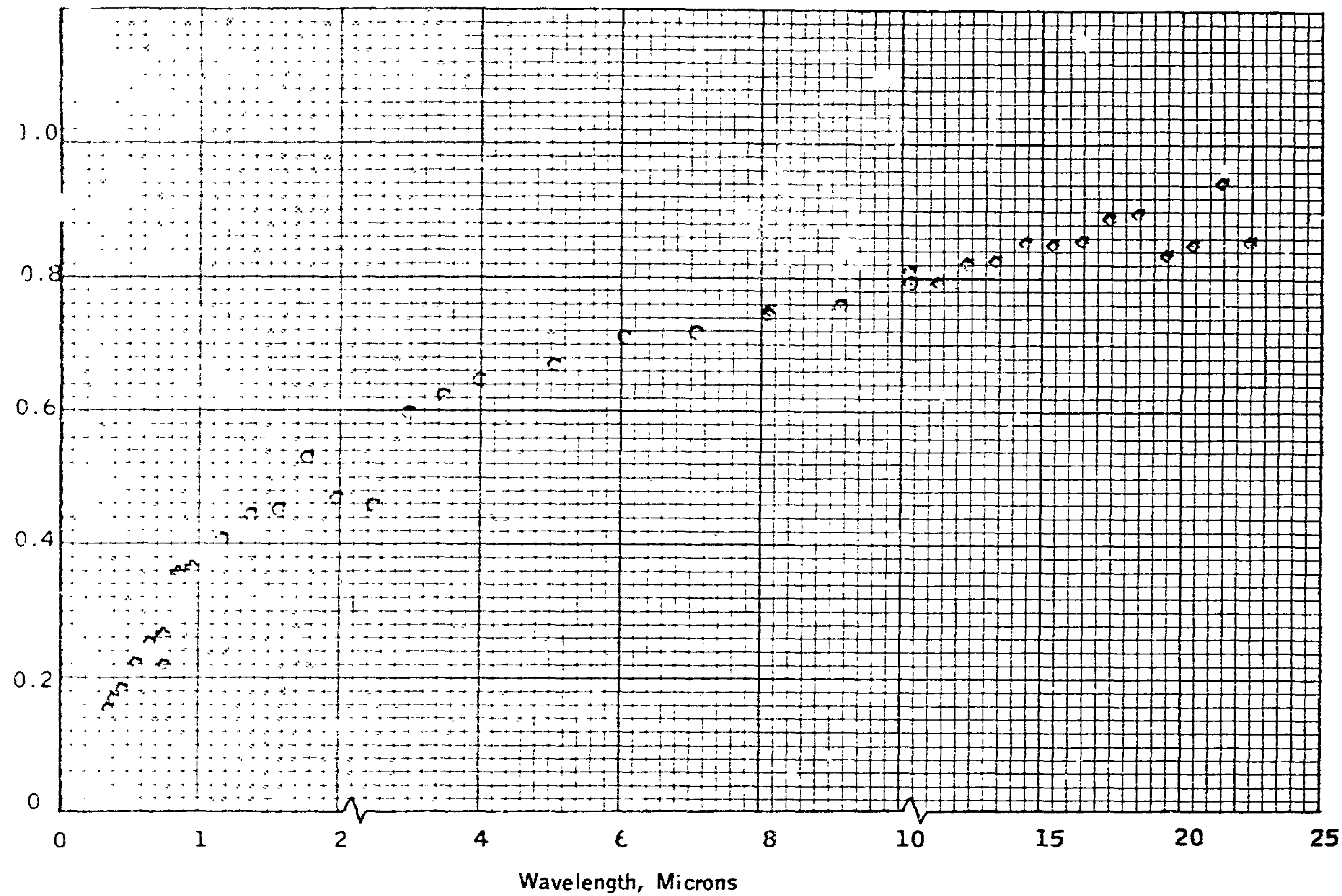


Fig. 144 Normal Spectral Reflectance of Specimen No 48 Temperature 1300 F

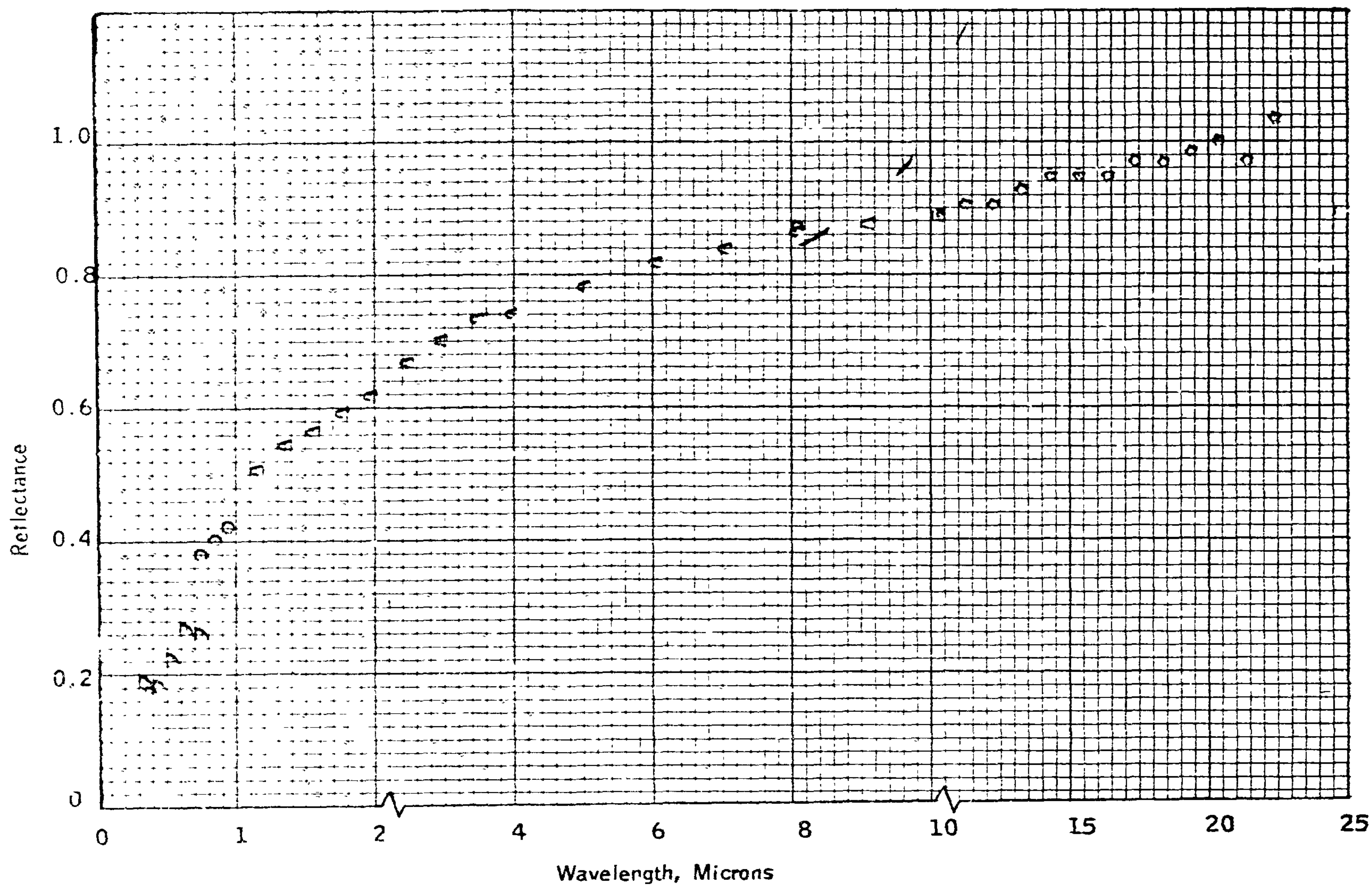


Fig 145 Normal Spectral Reflectance of Specimen No 48 Temperature RT_f (1300 F)

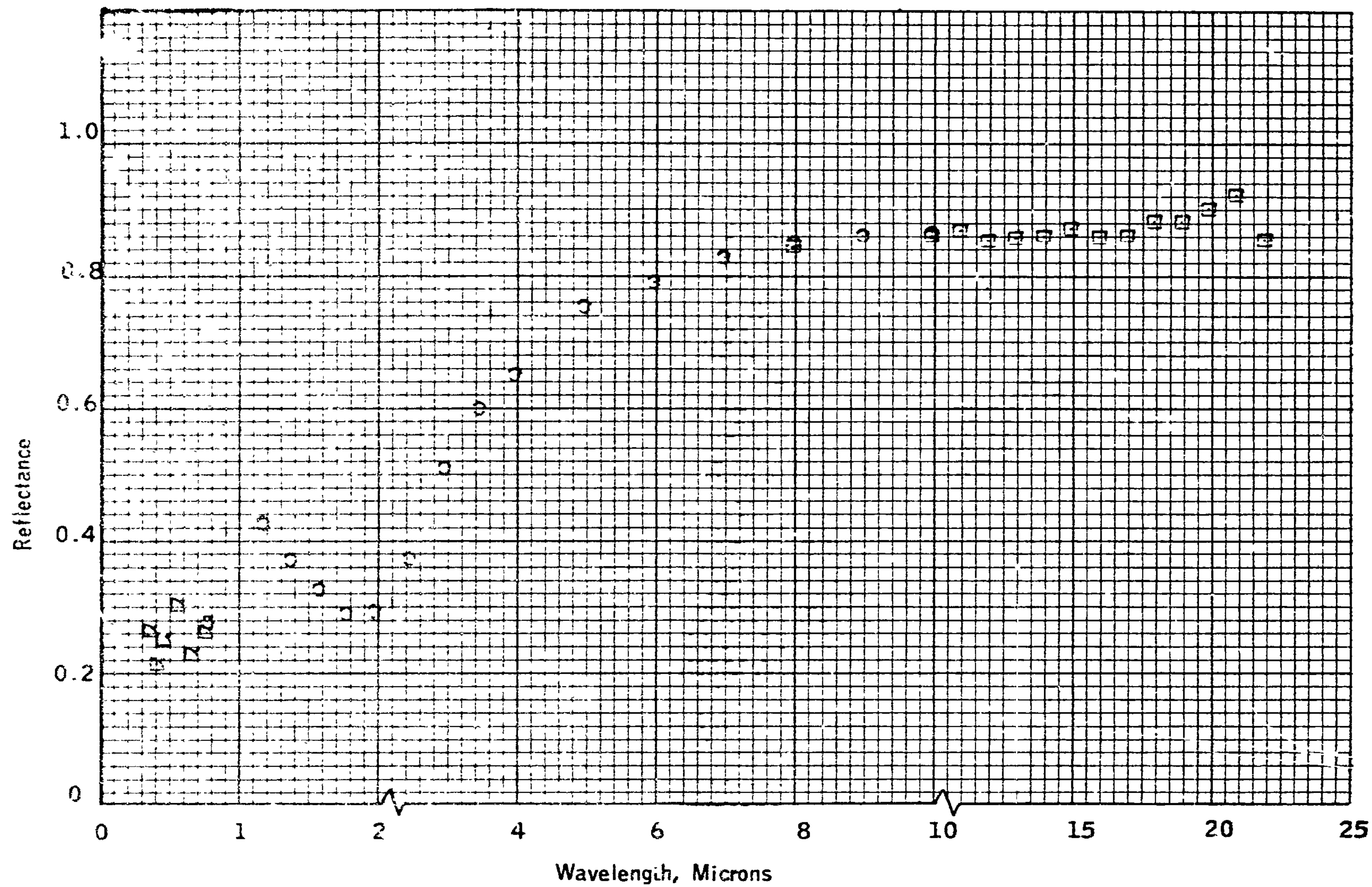


Fig. 146 Normal Spectral Reflectance of Specimen No 178 Temperature RT

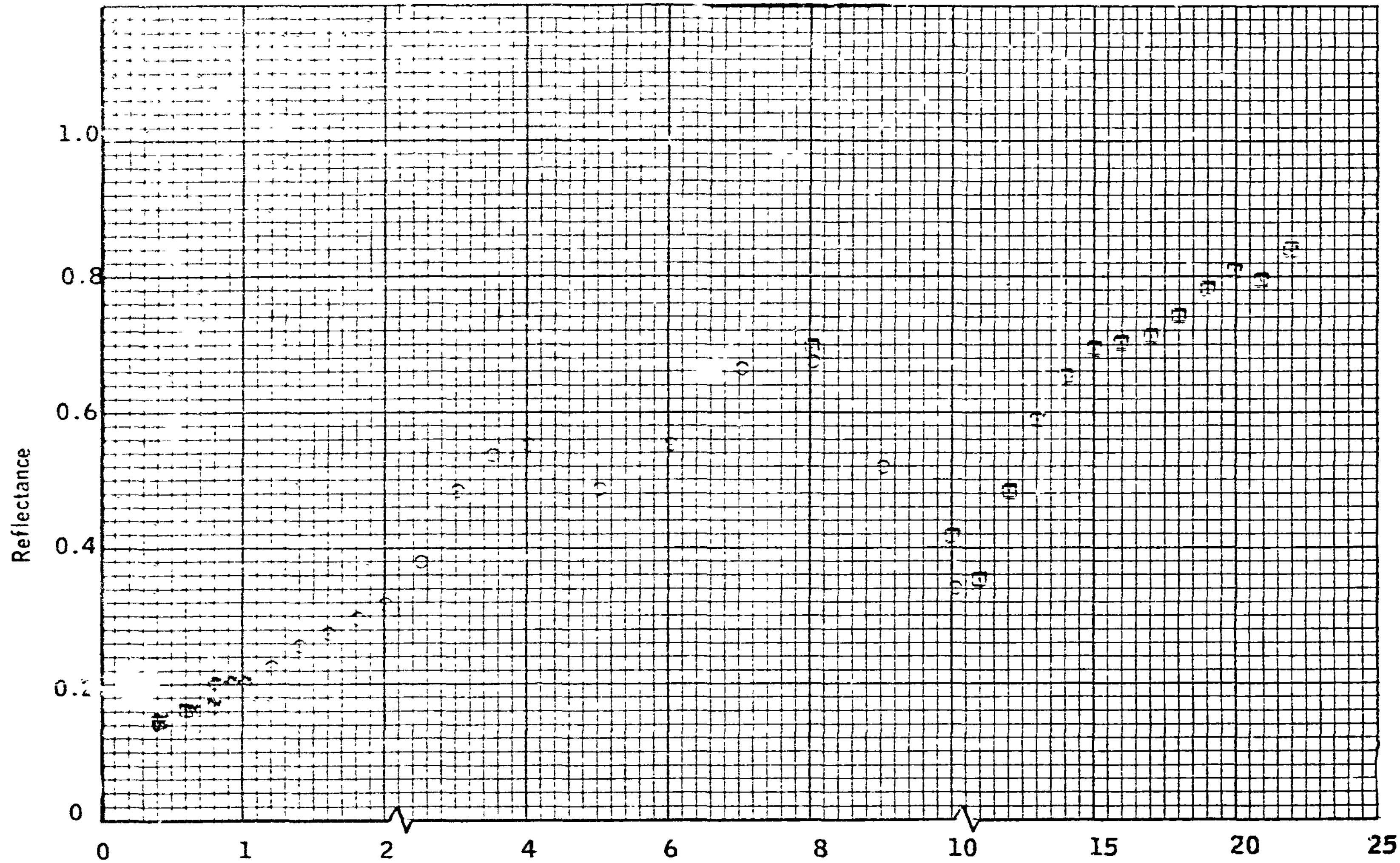


Fig. 147 Normal Spectral Reflectance of Specimen No 37 Temperature RT

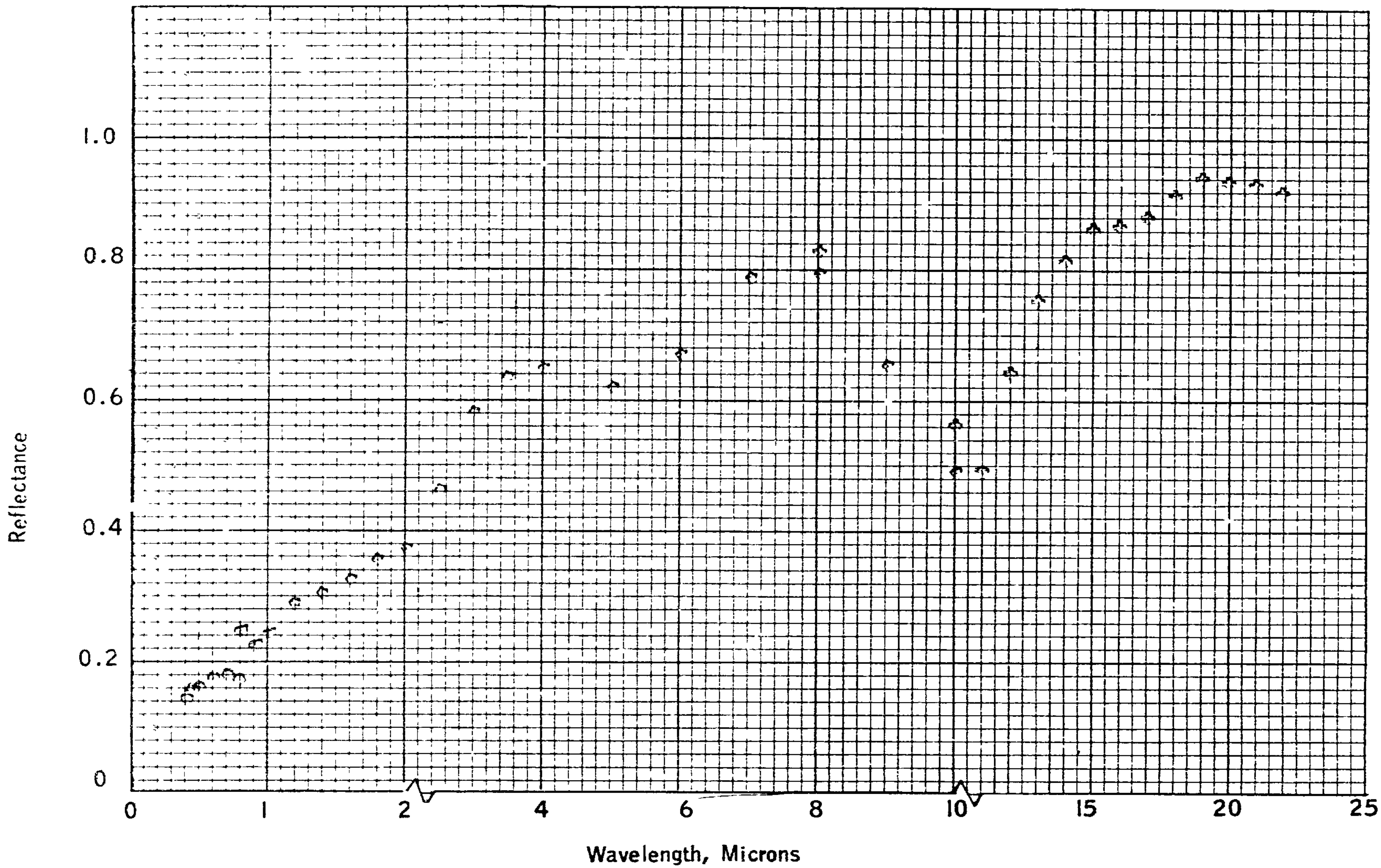


Fig. 148 Normal Spectral Reflectance of Specimen No 41 Temperature RT

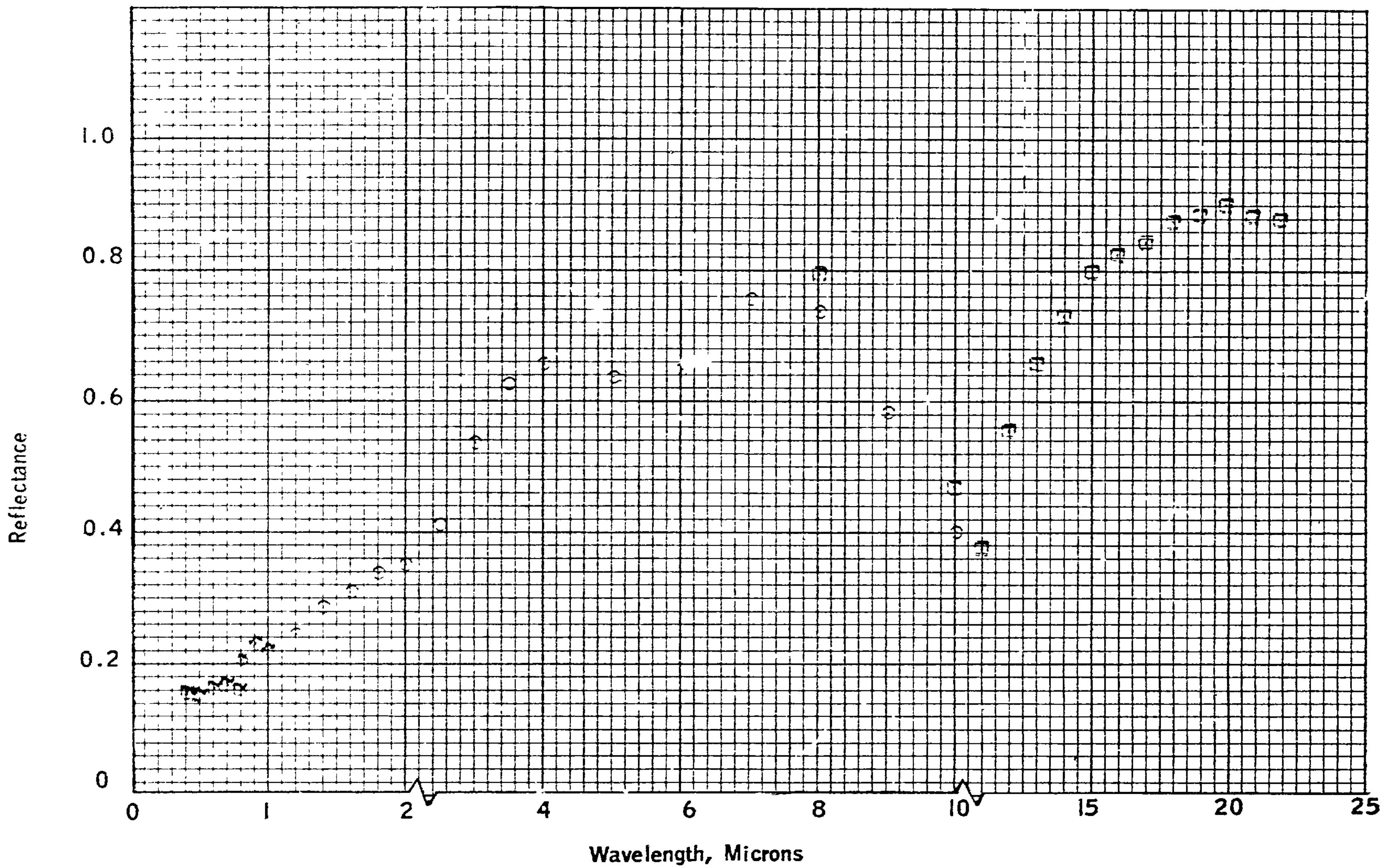


Fig. 149 Normal Spectral Reflectance of Specimen No 47 Temperature RT

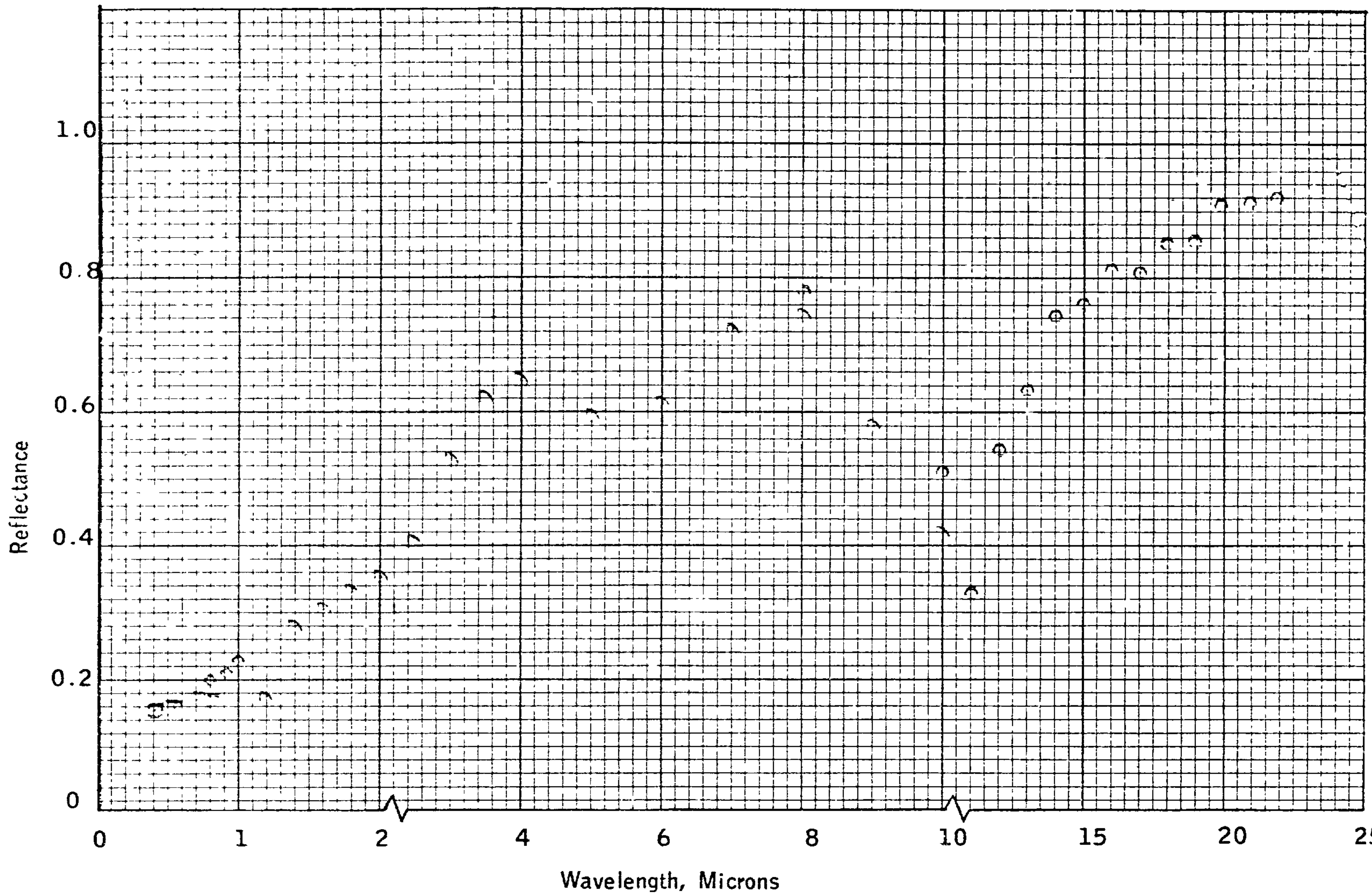


Fig. 150 Normal Spectral Reflectance of Specimen No 47 Temperature 500F

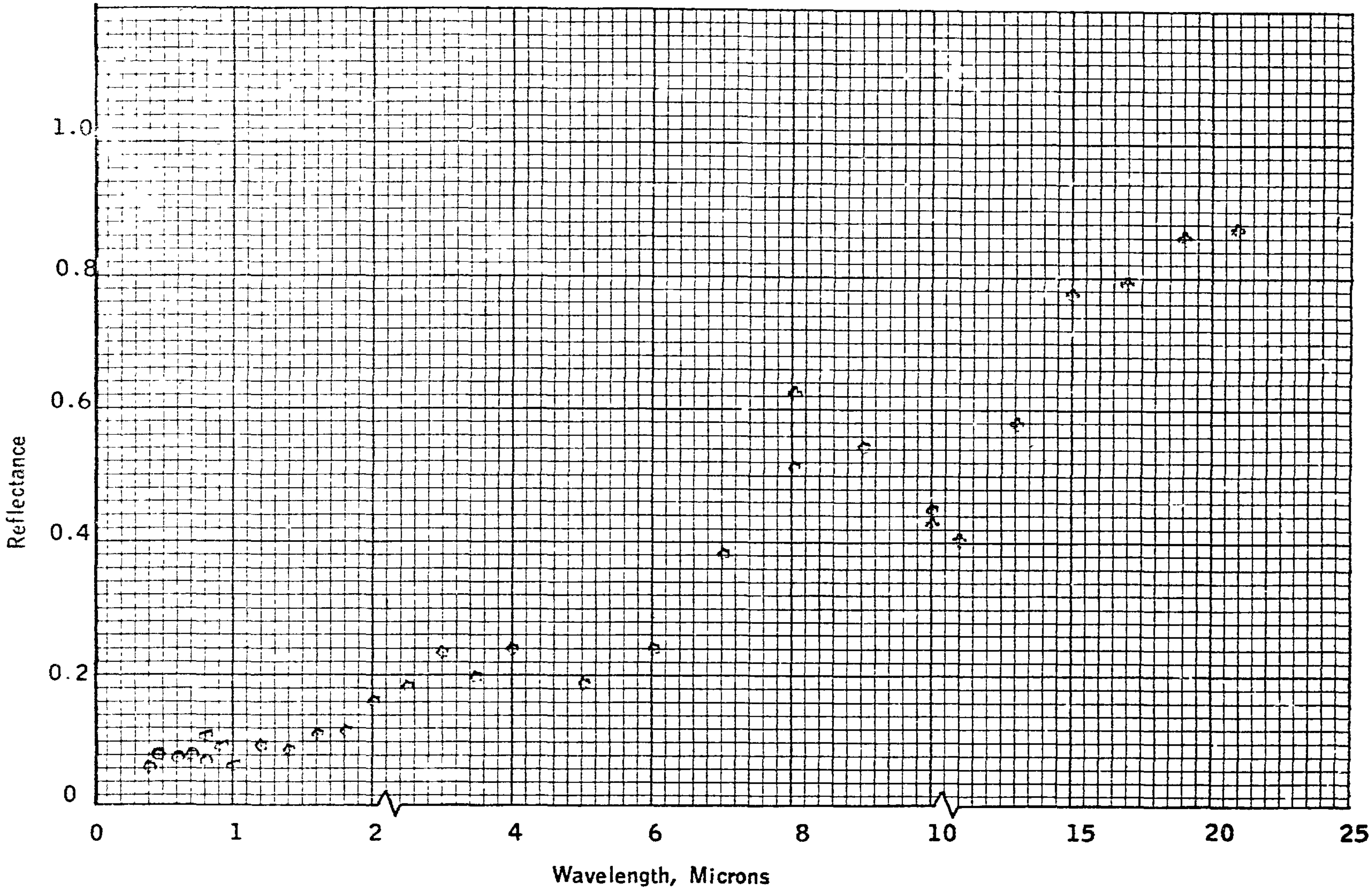


Fig. 151 Normal Spectral Reflectance of Specimen No 47 Temperature 1000F

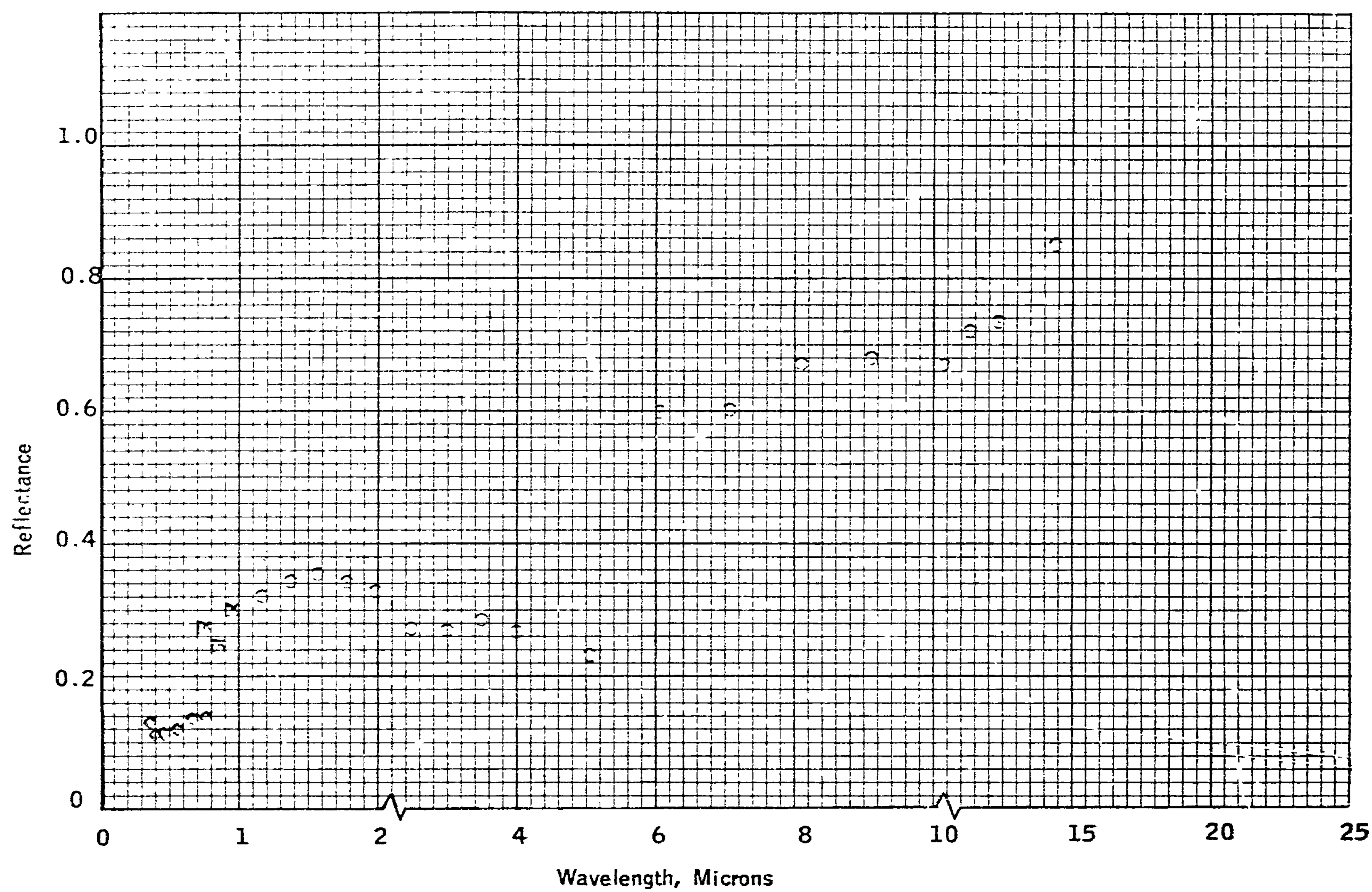


Fig. 152 Normal Spectral Reflectance of Specimen No 47 Temperature 1300 F

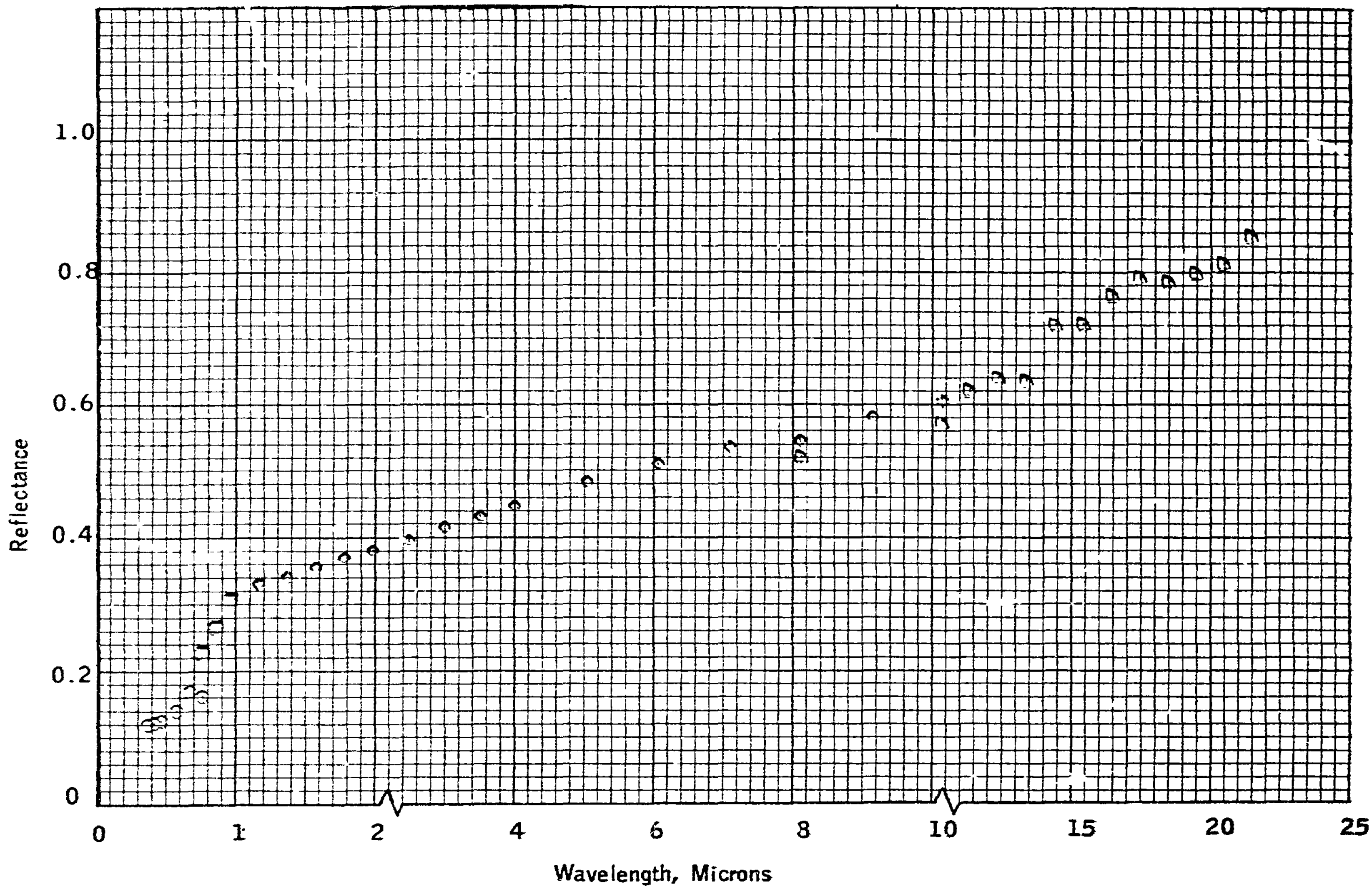


Fig. 153 Normal Spectral Reflectance of Specimen No 47 Temperature RT_f

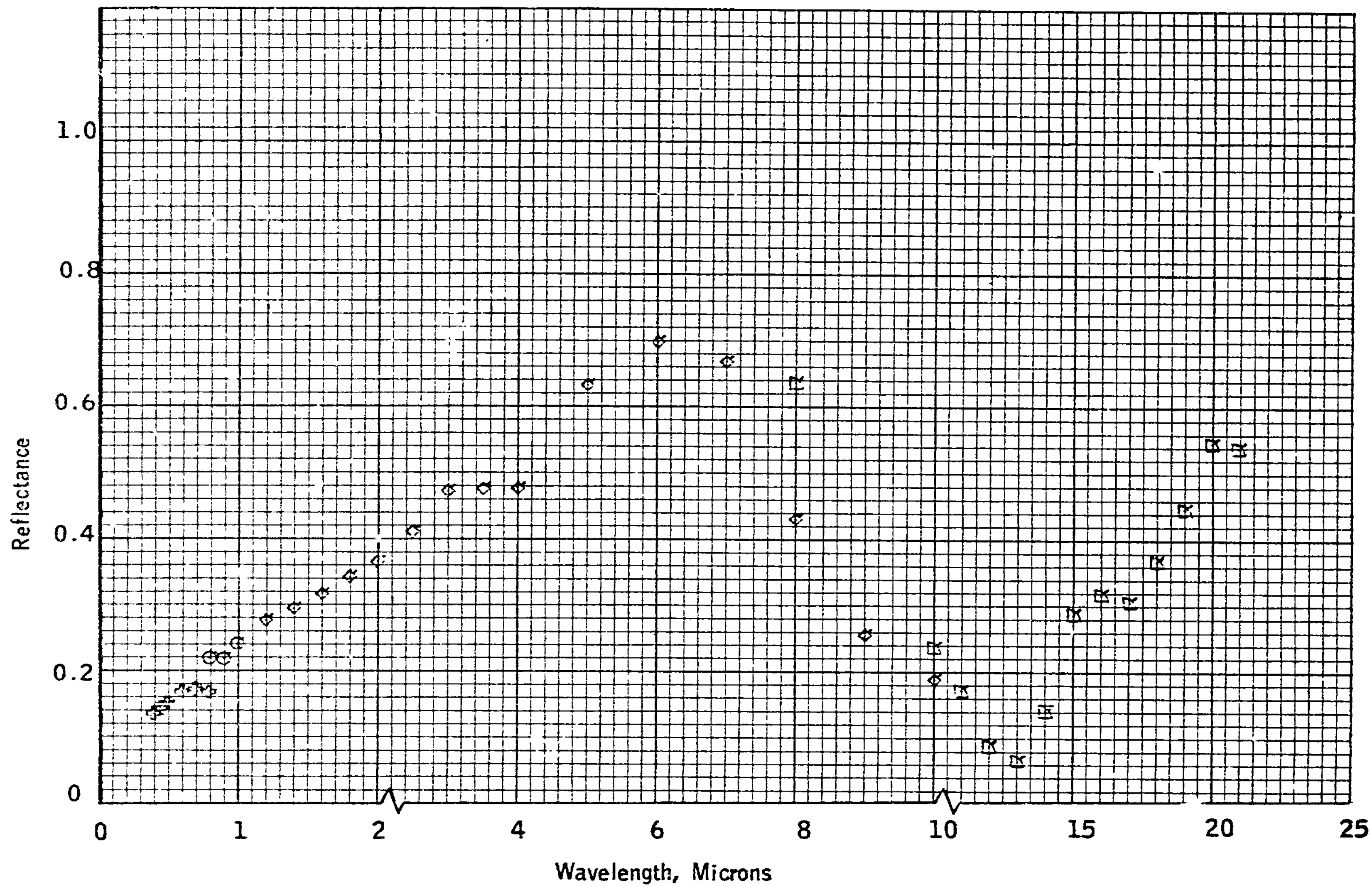


Fig. 154 Normal Spectral Reflectance of Specimen No 197 Temperature RT

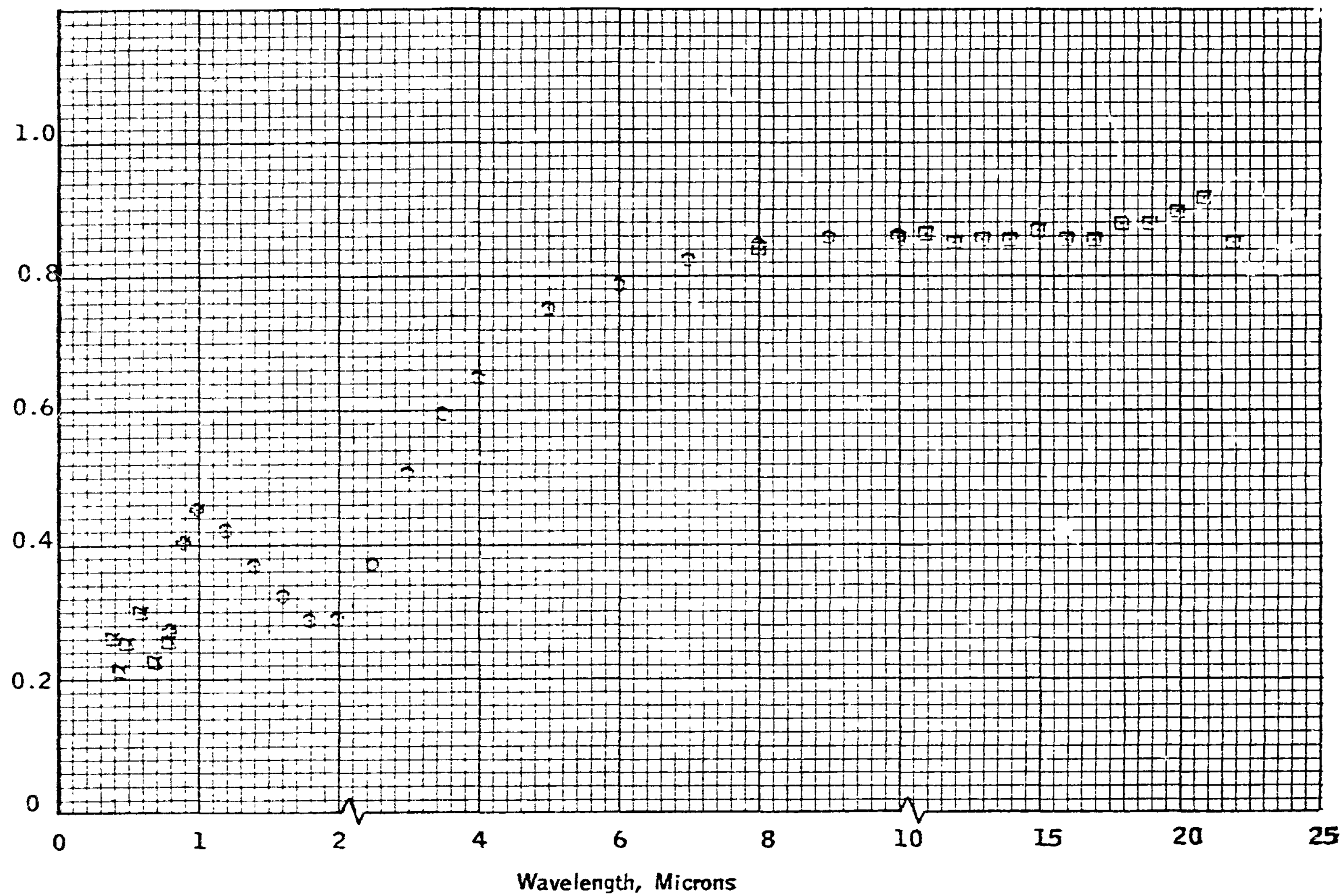


Fig. 155 Normal Spectral Reflectance of Specimen No 199 Temperature RT

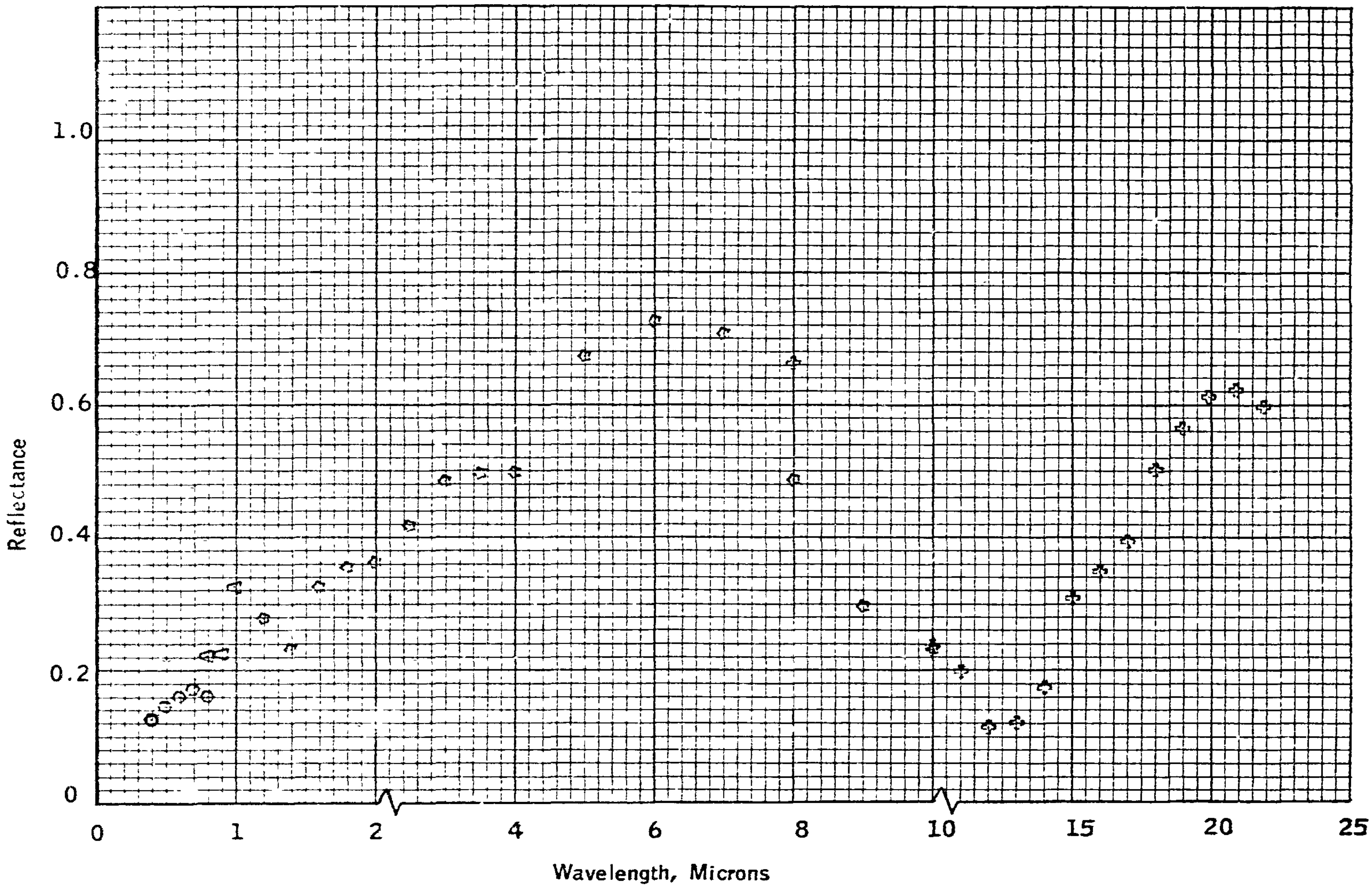


Fig. 156 Normal Spectral Reflectance of Specimen No 201 Temperature RT

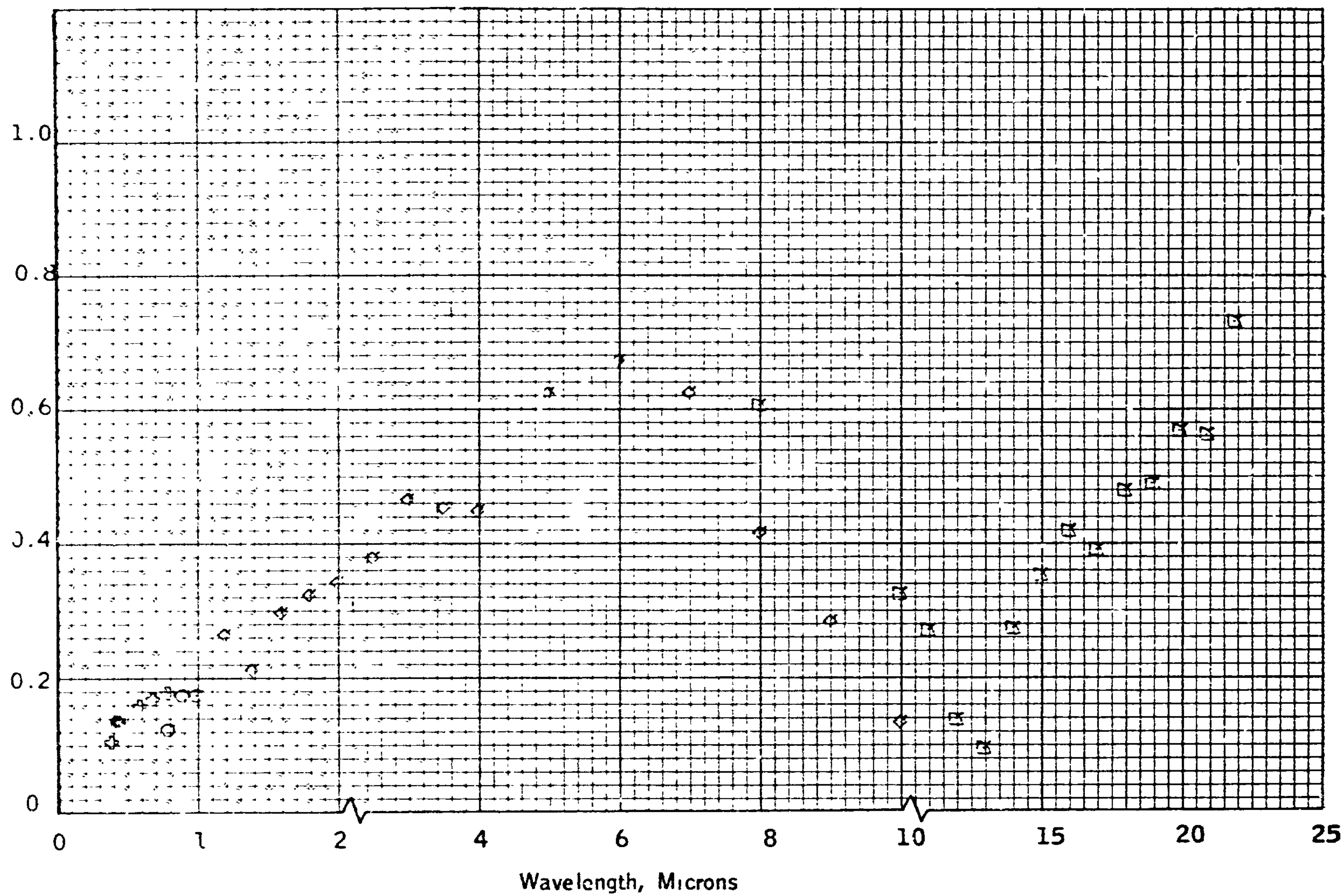


Fig. 157 Normal Spectral Reflectance of Specimen No 201 Temperature 500 F

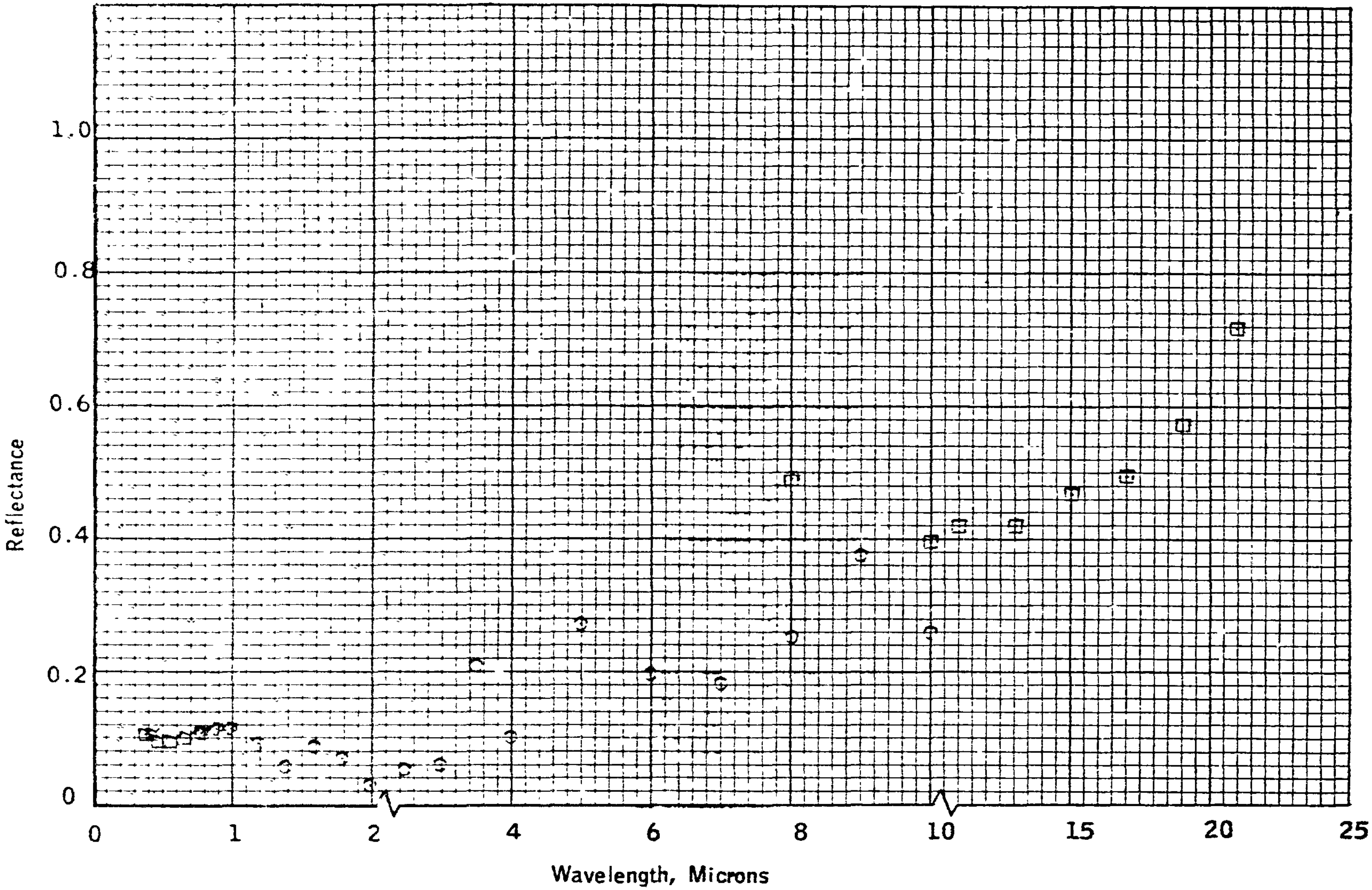


Fig. 158 Normal Spectral Reflectance of Specimen No 201 Temperature 1000F

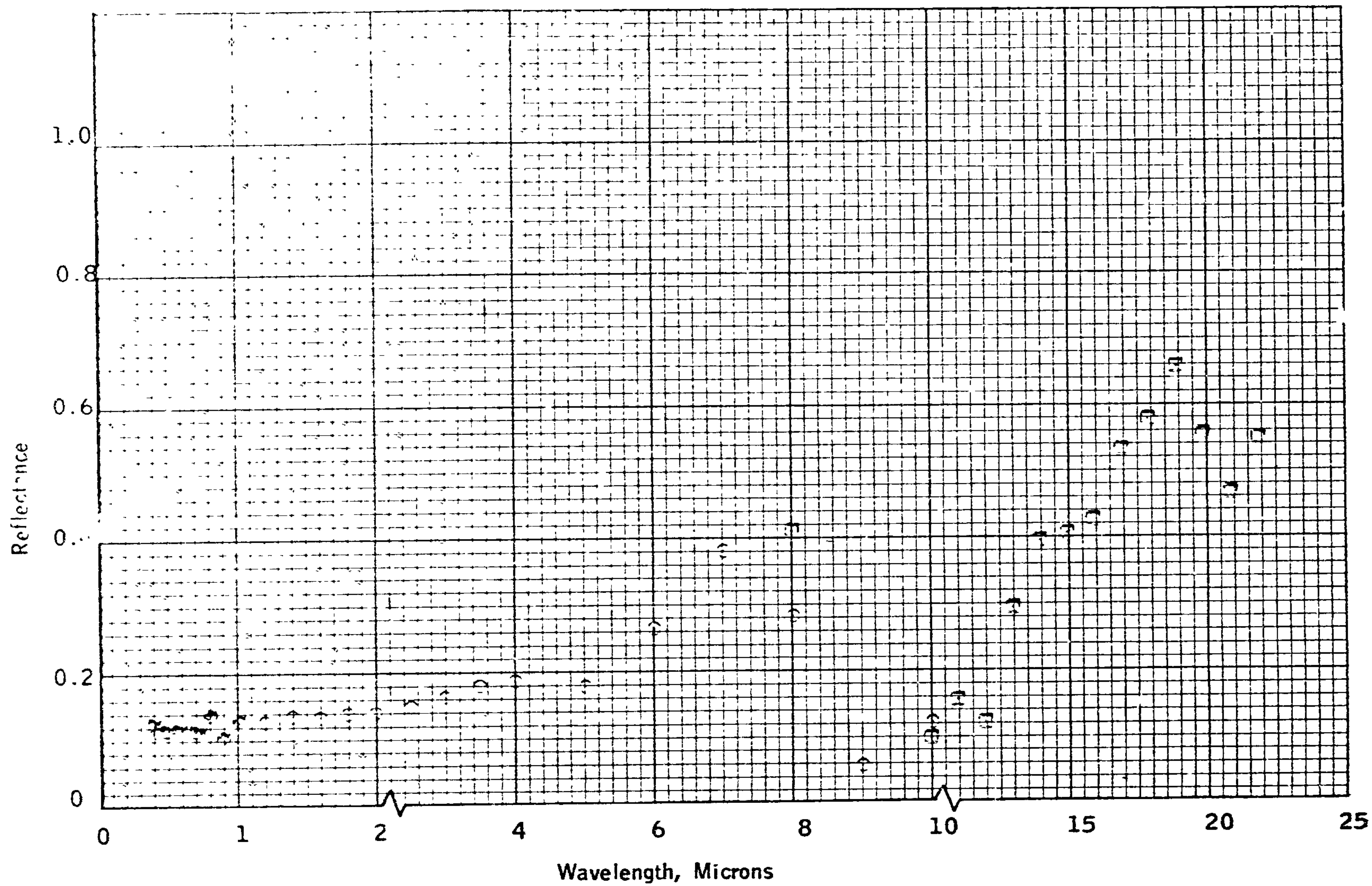


Fig. 159 Normal Spectral Reflectance of Specimen No 201 Temperature RT, HT-1500F

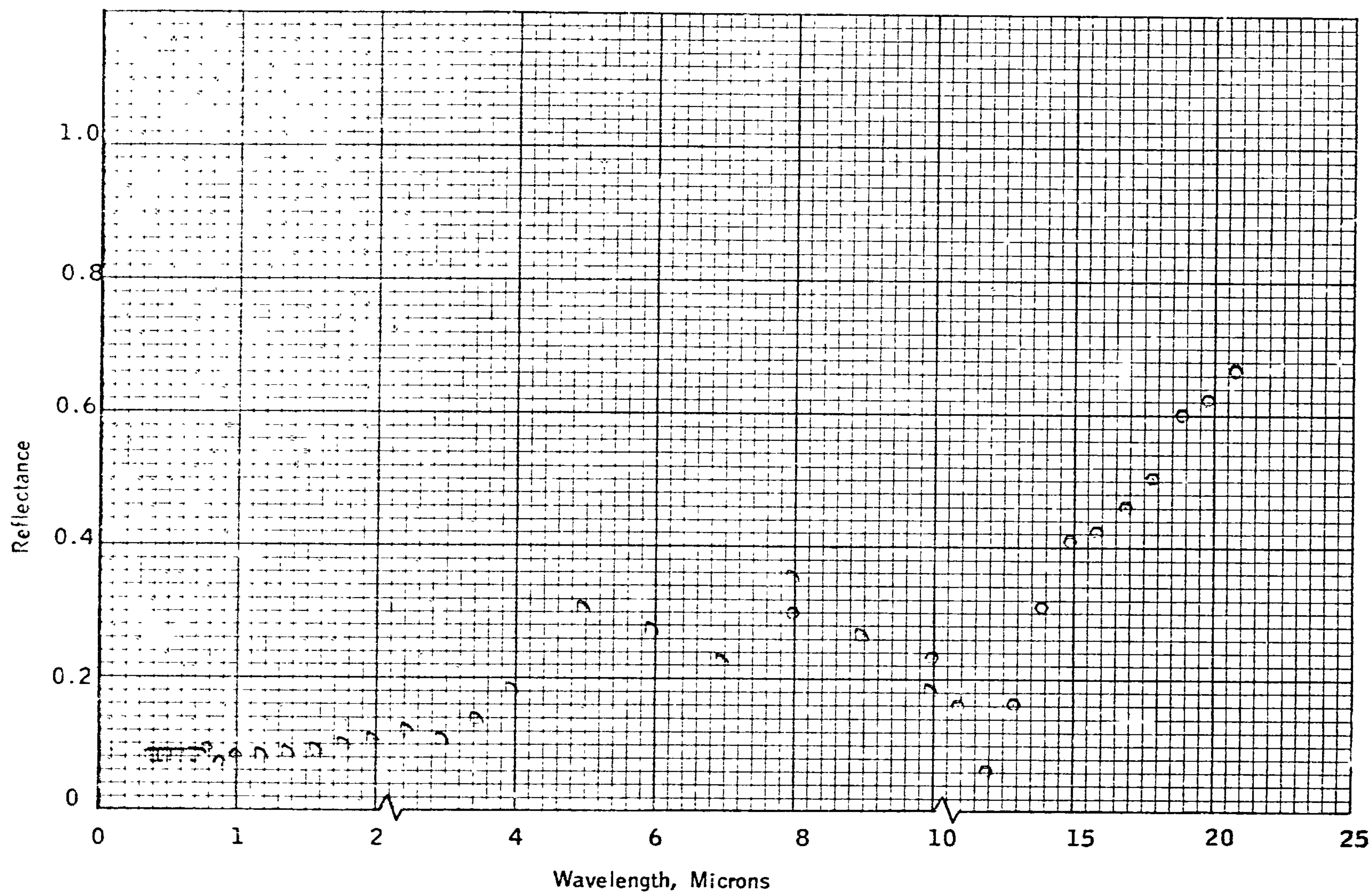


Fig. 160 Normal Spectral Reflectance of Specimen No 201 Temperature RT_f

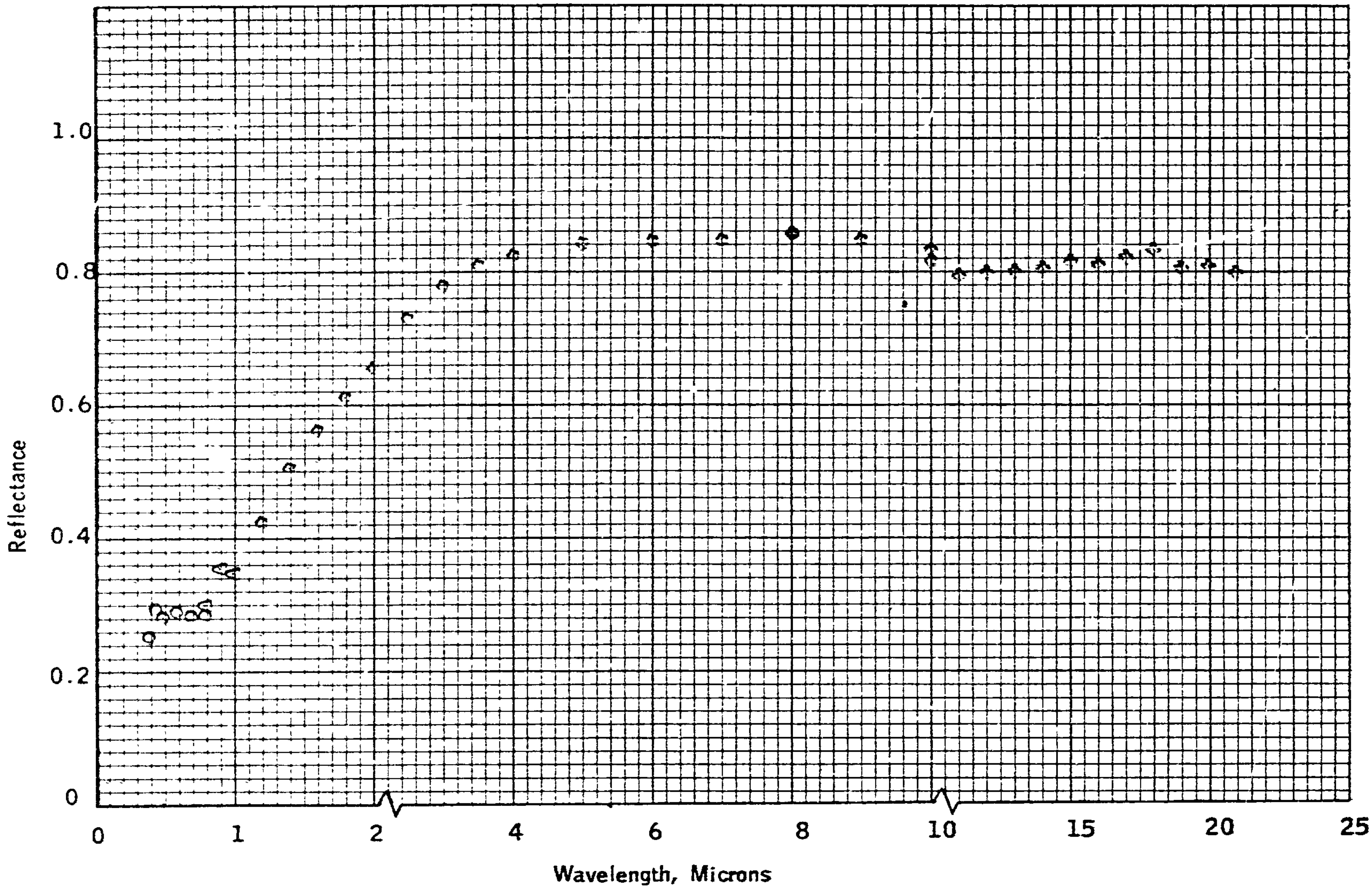


Fig.161 Normal Spectral Reflectance of Specimen No 162 Temperature RT

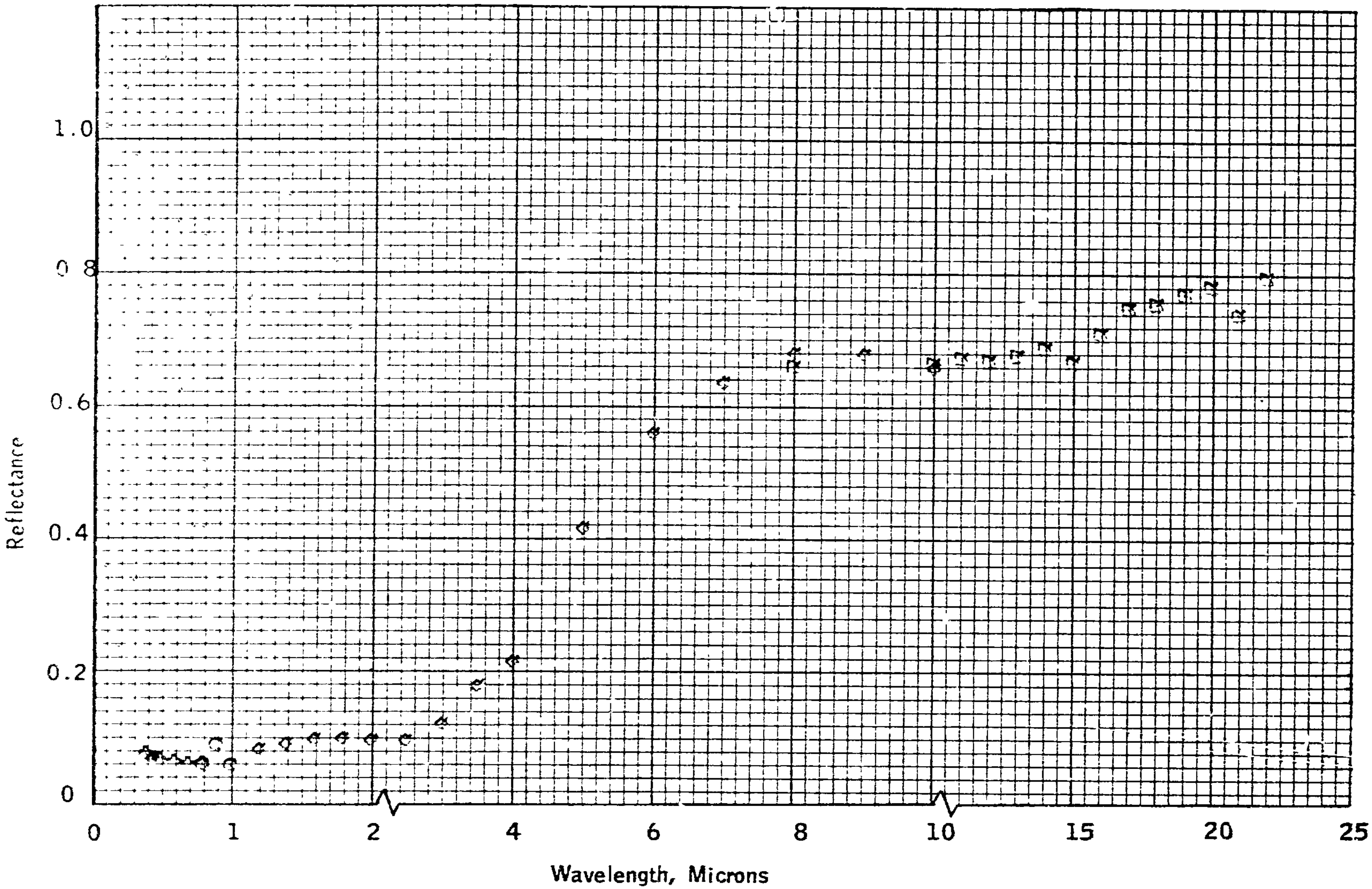


Fig. 162 Normal Spectral Reflectance of Specimen No 164 Temperature RT

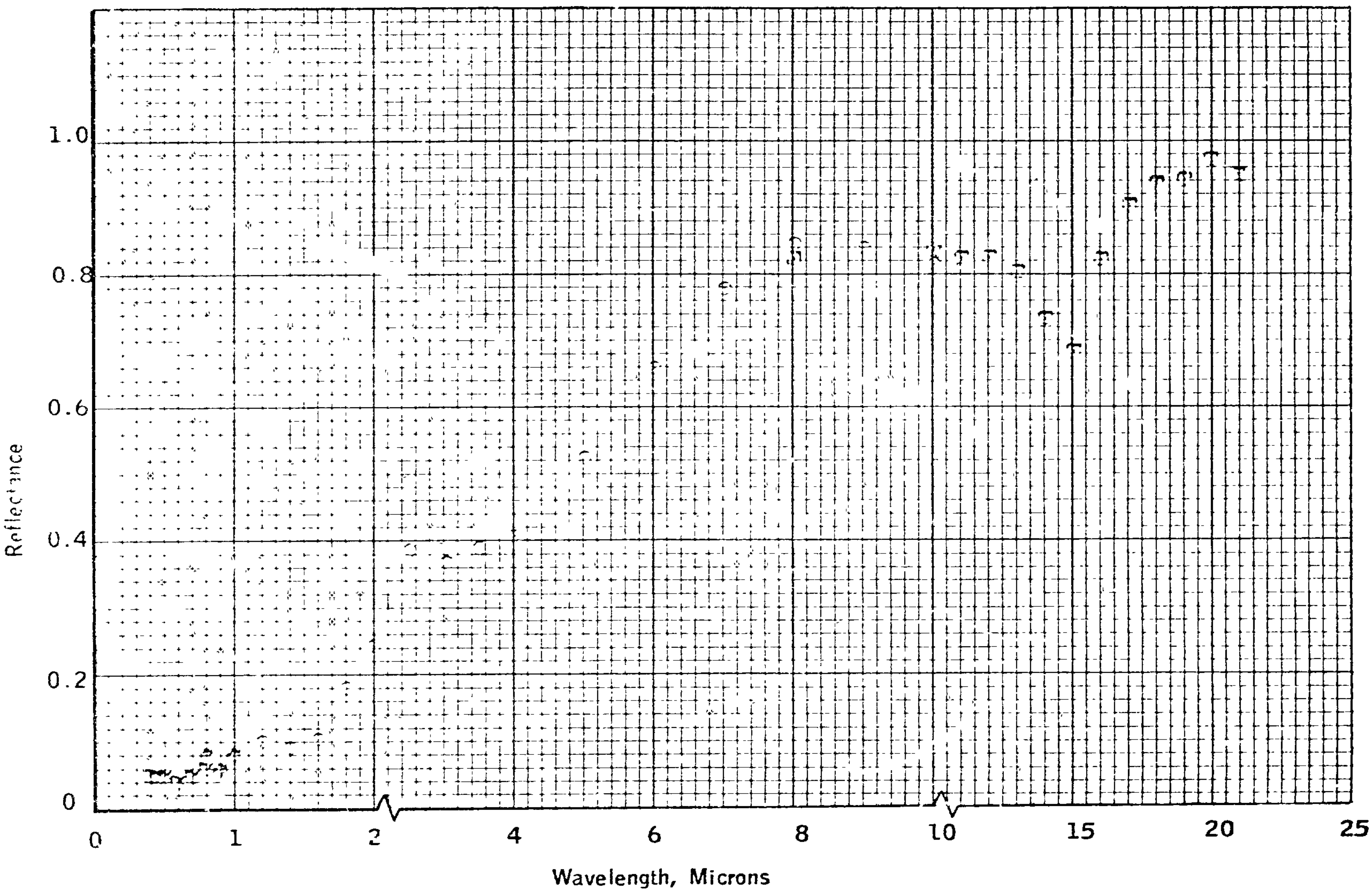


Fig. 163 Normal Spectral Reflectance of Specimen No 166 Temperature RT

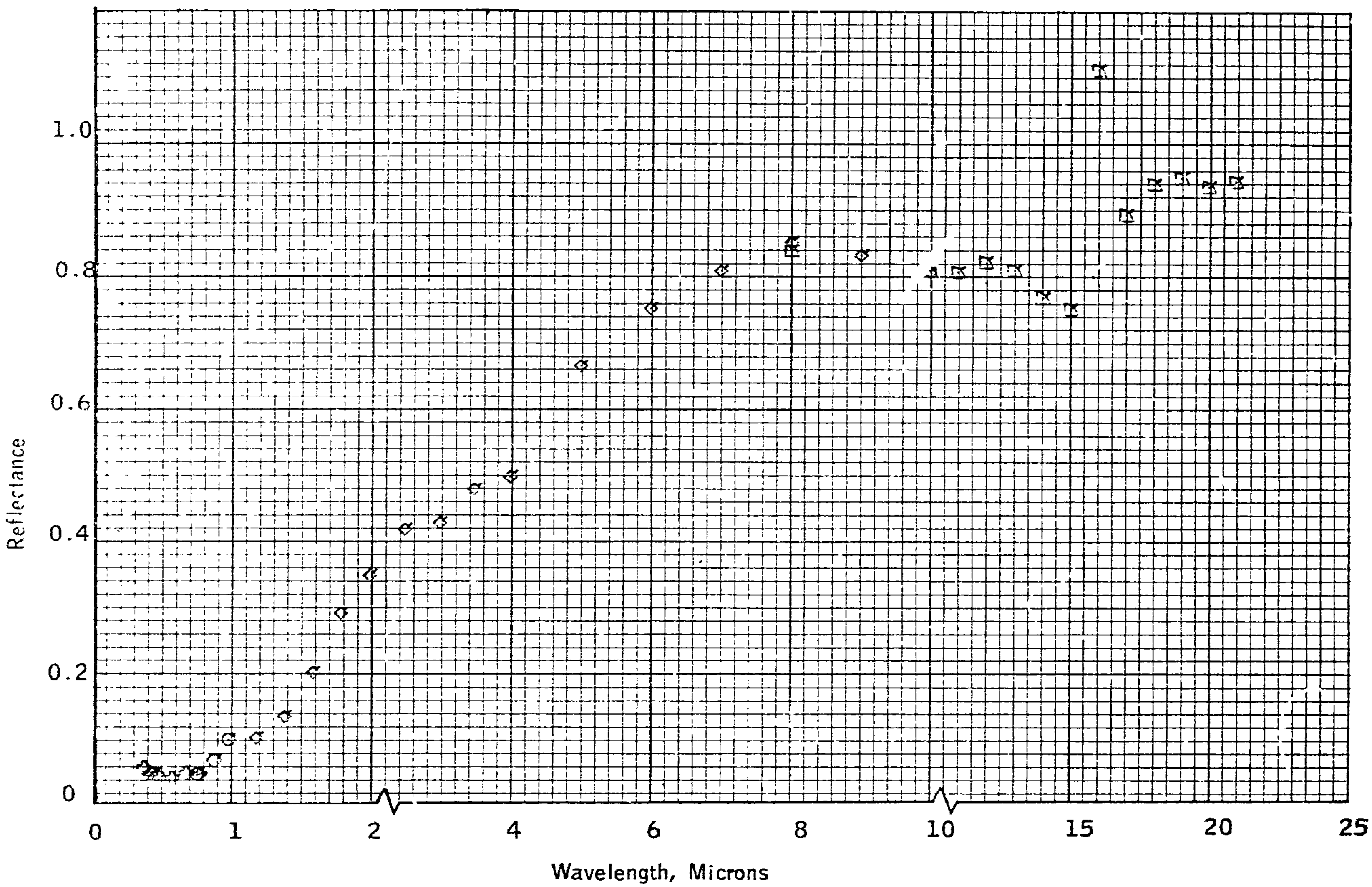


Fig. 164 Normal Spectral Reflectance of Specimen No 166 Temperature 400 F

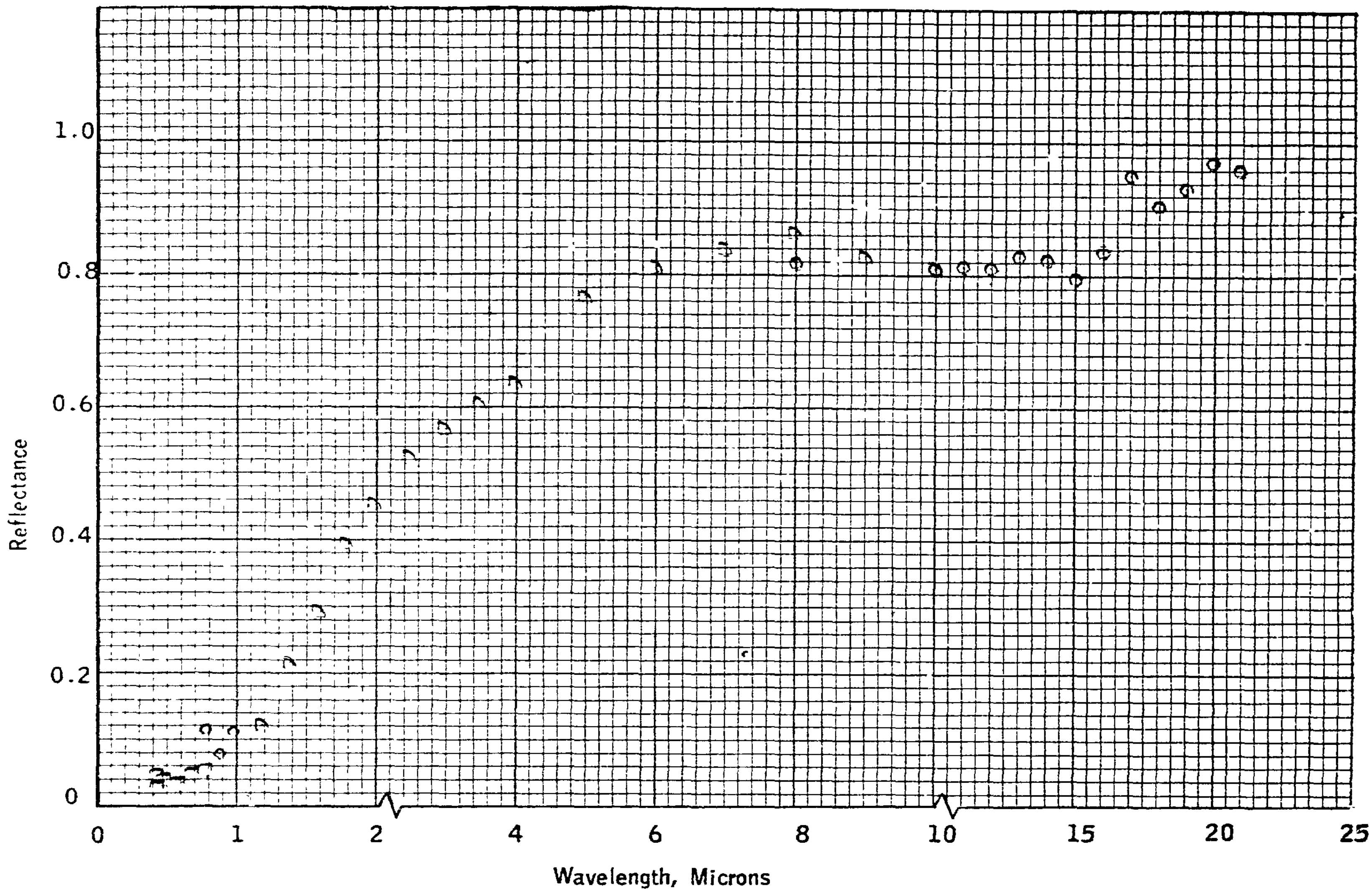


Fig. 165 Normal Spectral Reflectance of Specimen No 166 Temperature 800 F

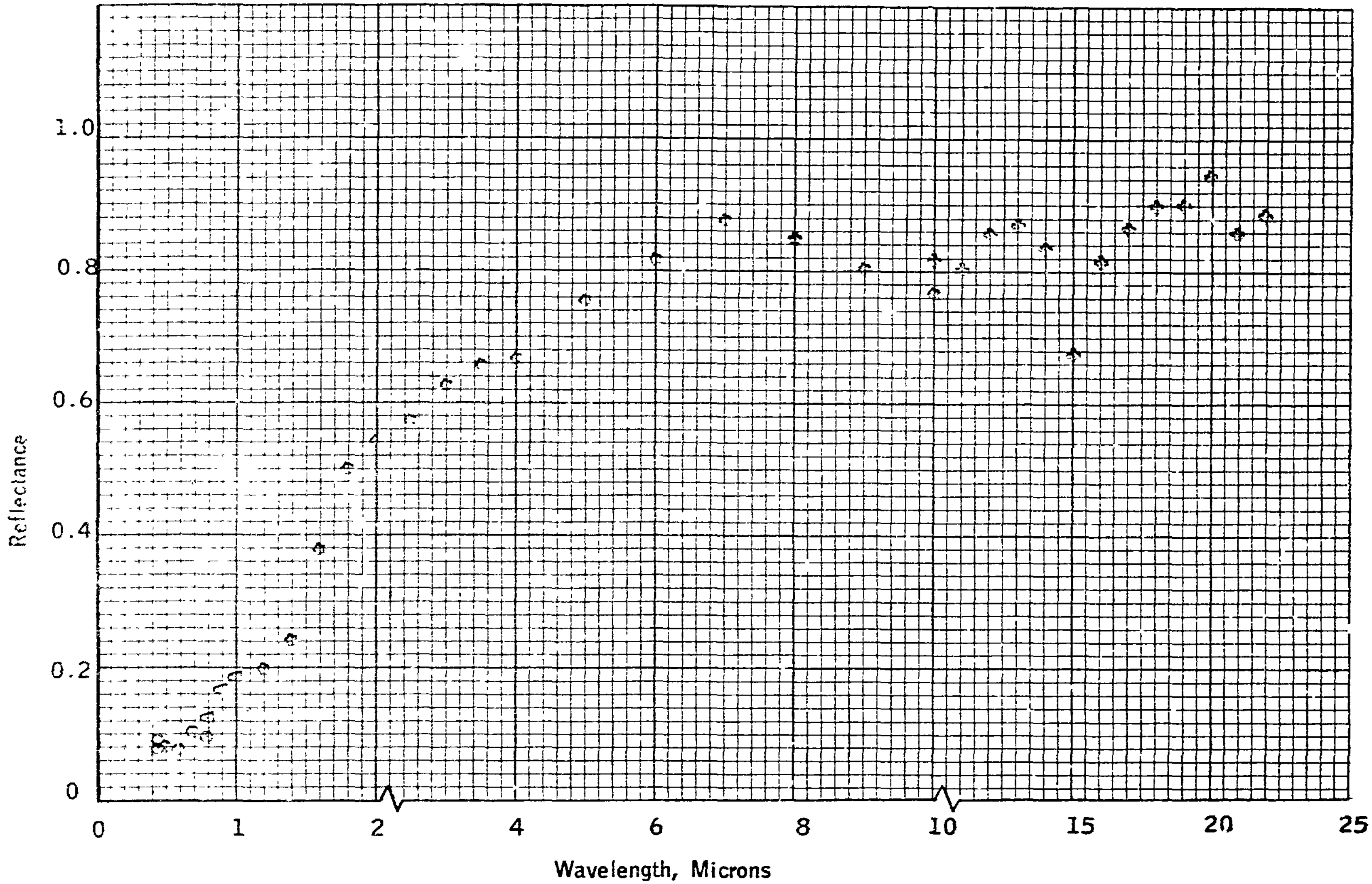


Fig. 166 Normal Spectral Reflectance of Specimen No 166 Temperature 1200 F

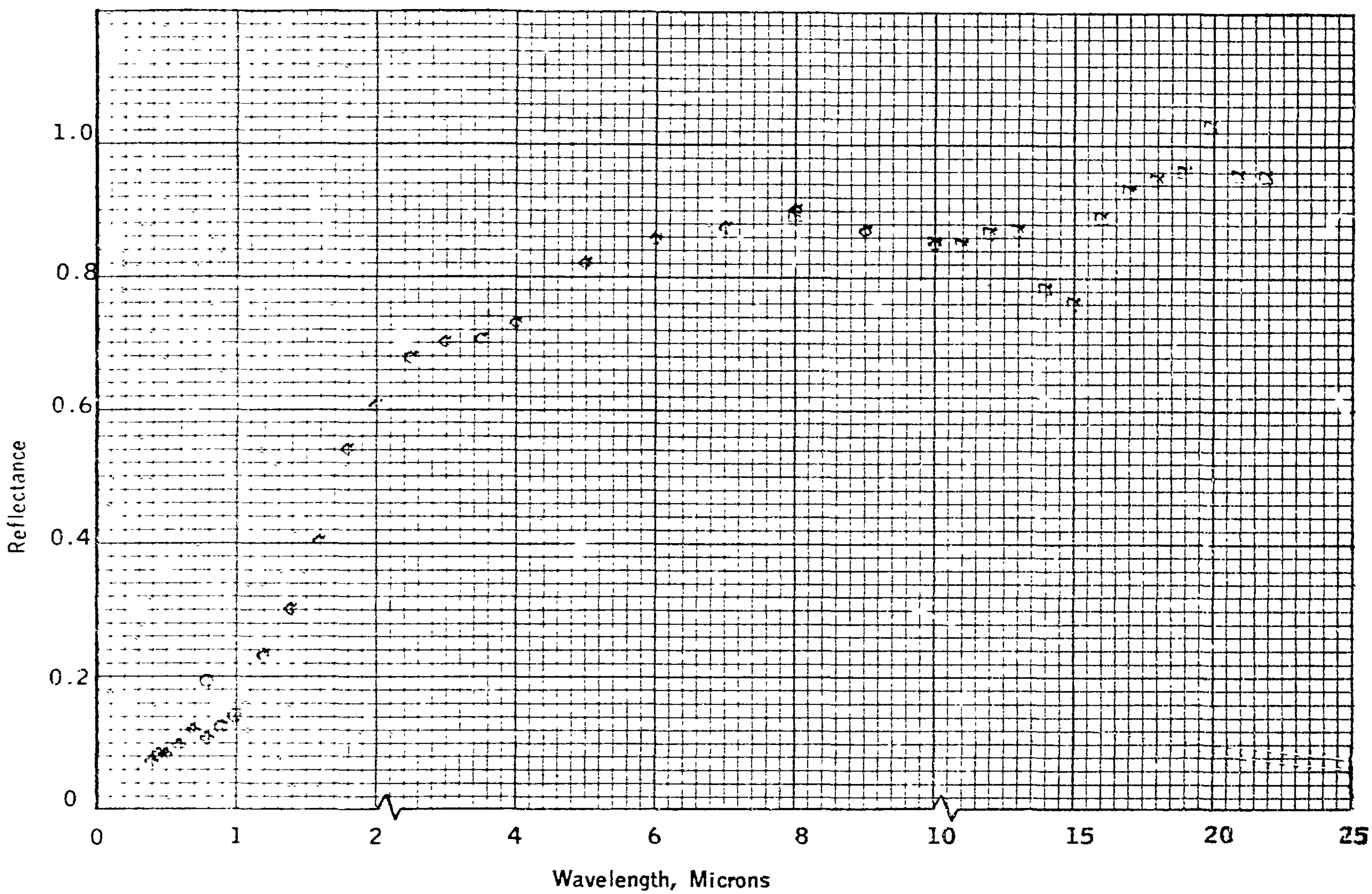


Fig. 167 Normal Spectral Reflectance of Specimen No 166 Tempera..ure RT_f

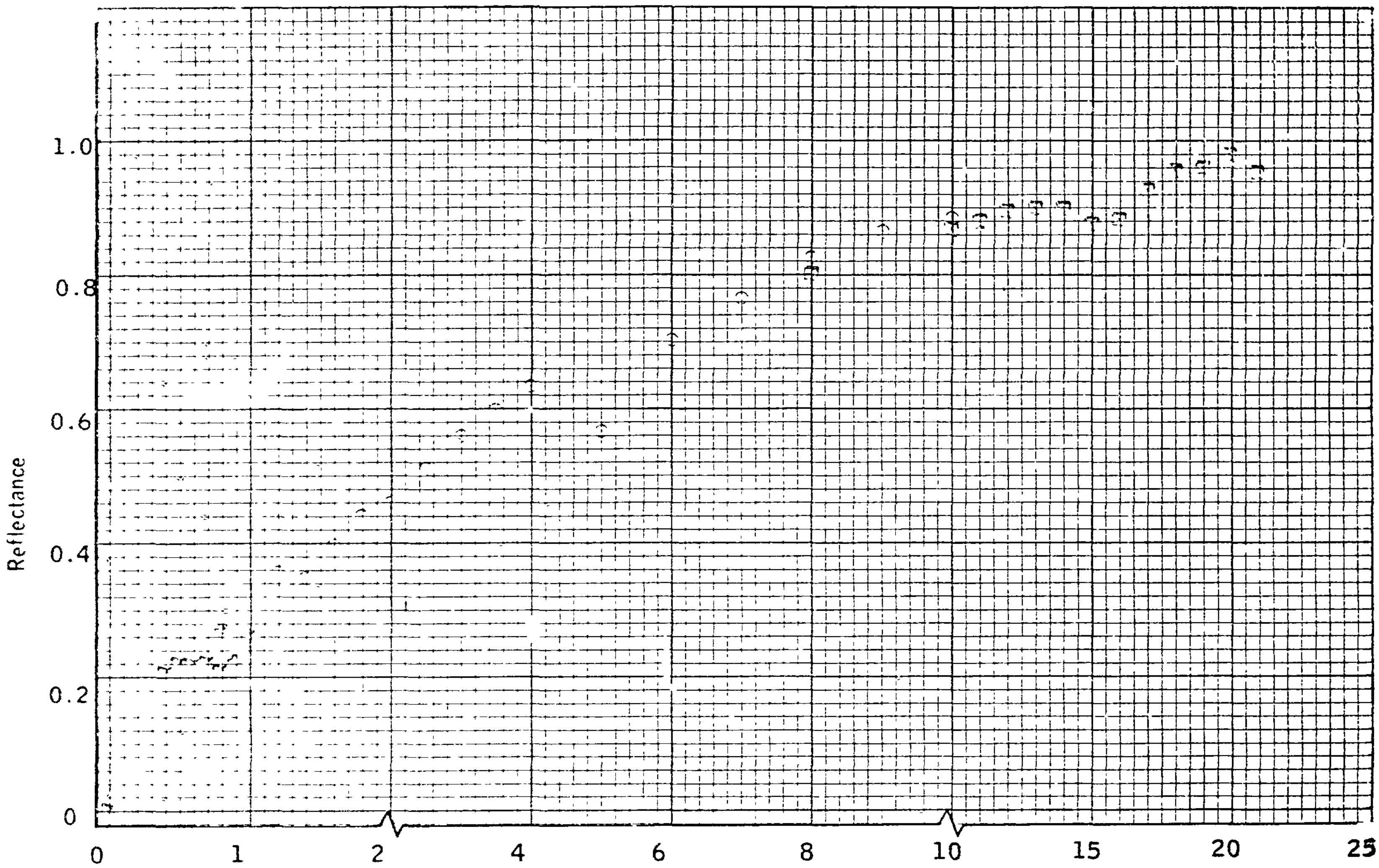


Fig. 168 Normal Spectral Reflectance of Specimen No 173 Temperature RT

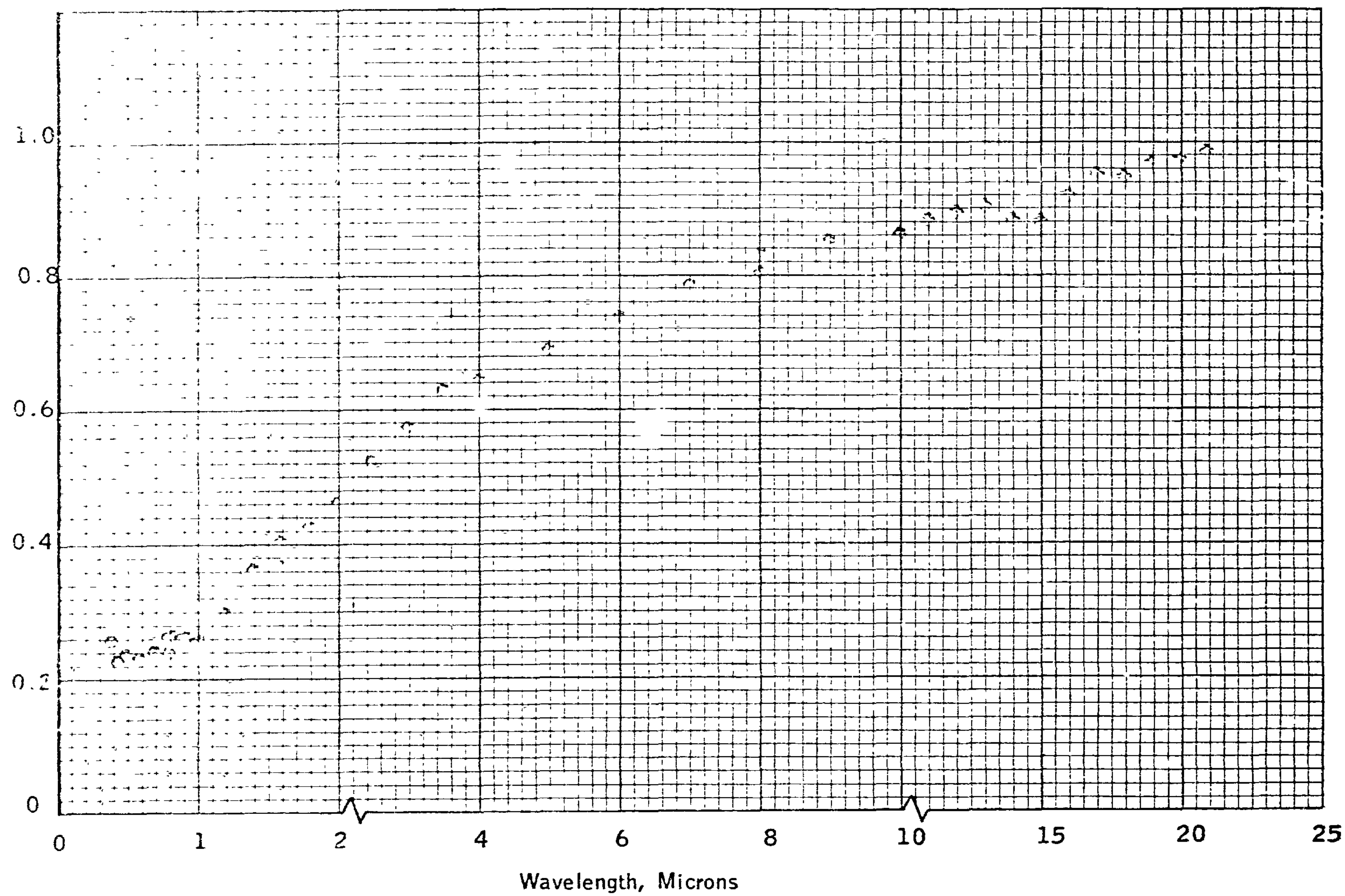


Fig. 169 Normal Spectral Reflectance of Specimen No 173 Temperature 400F

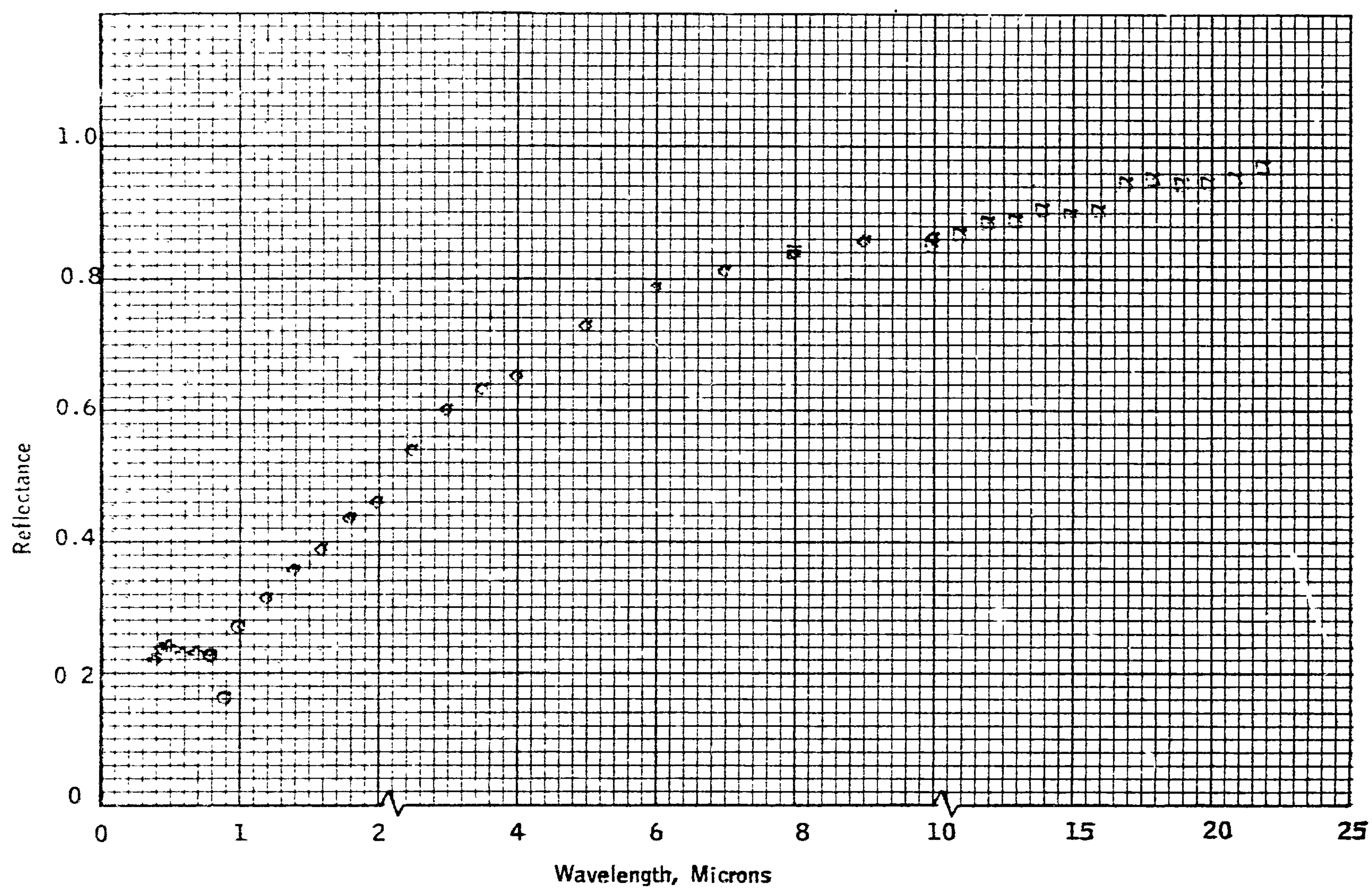


Fig. 170 Normal Spectral Reflectance of Specimen No 173 Temperature 800 F

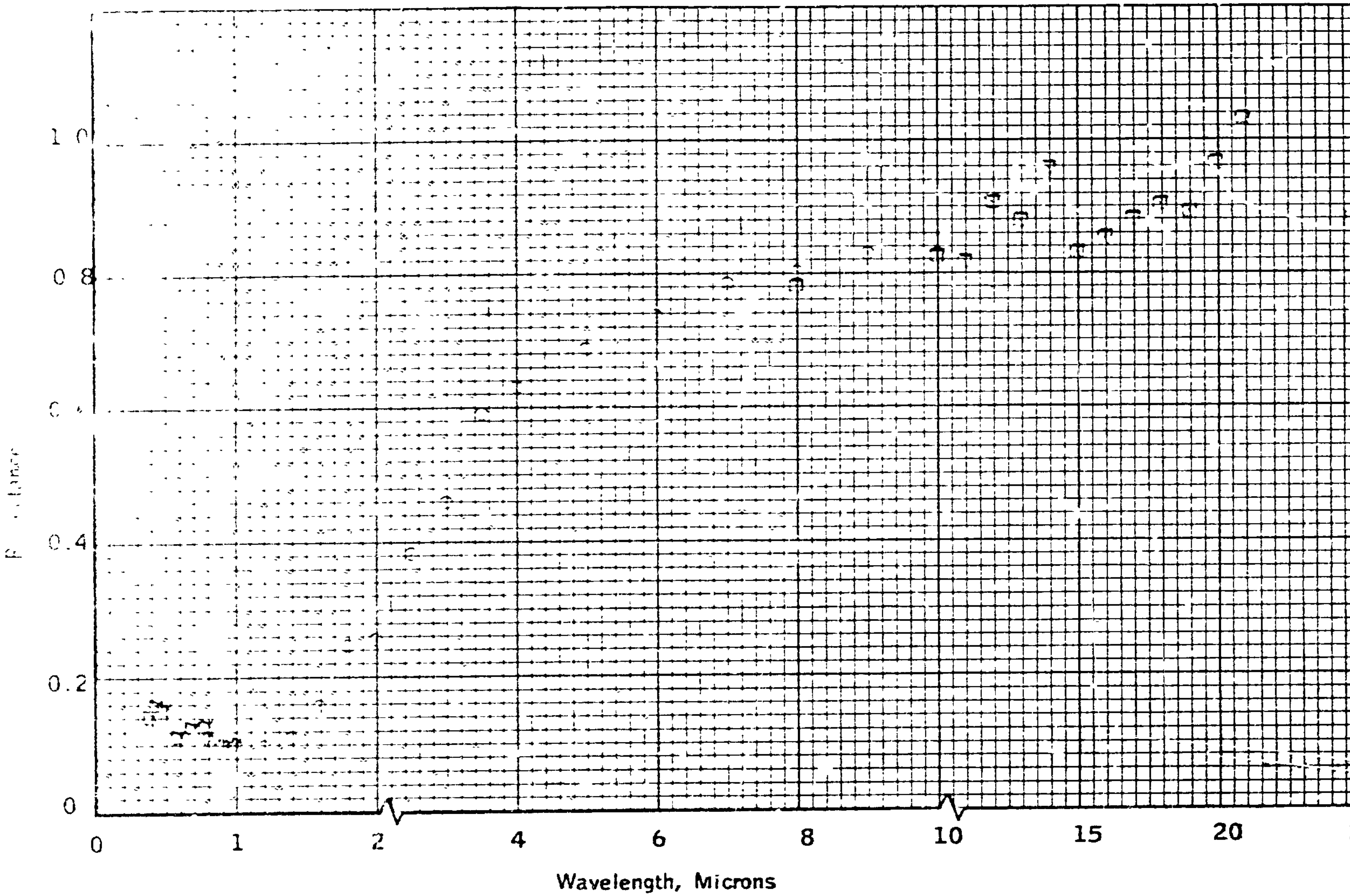


Fig. 171 Normal Spectral Reflectance of Specimen No 173 Temperature 1200 F

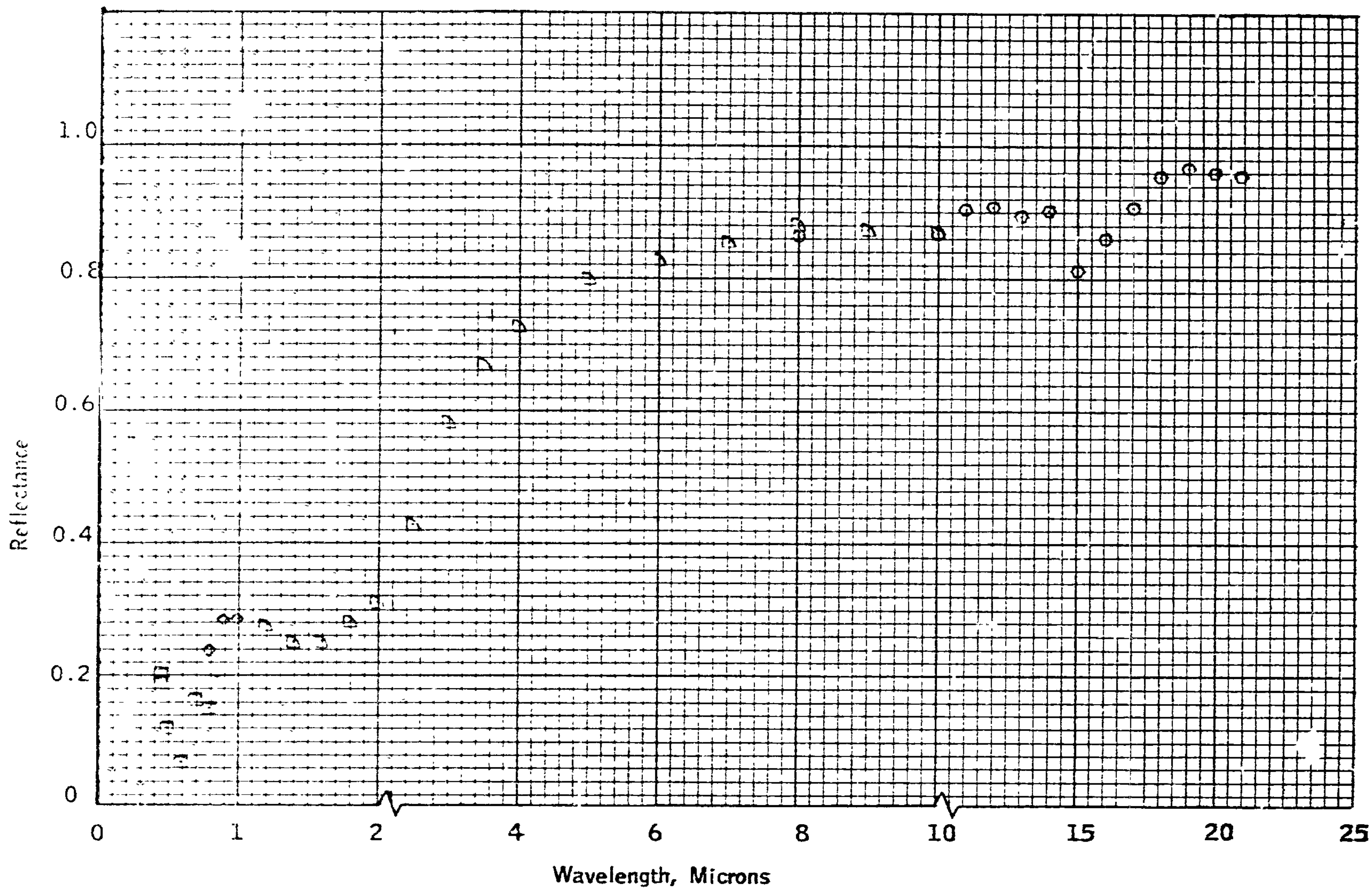


Fig. 172 Normal Spectral Reflectance of Specimen No 173 Temperature RT_f

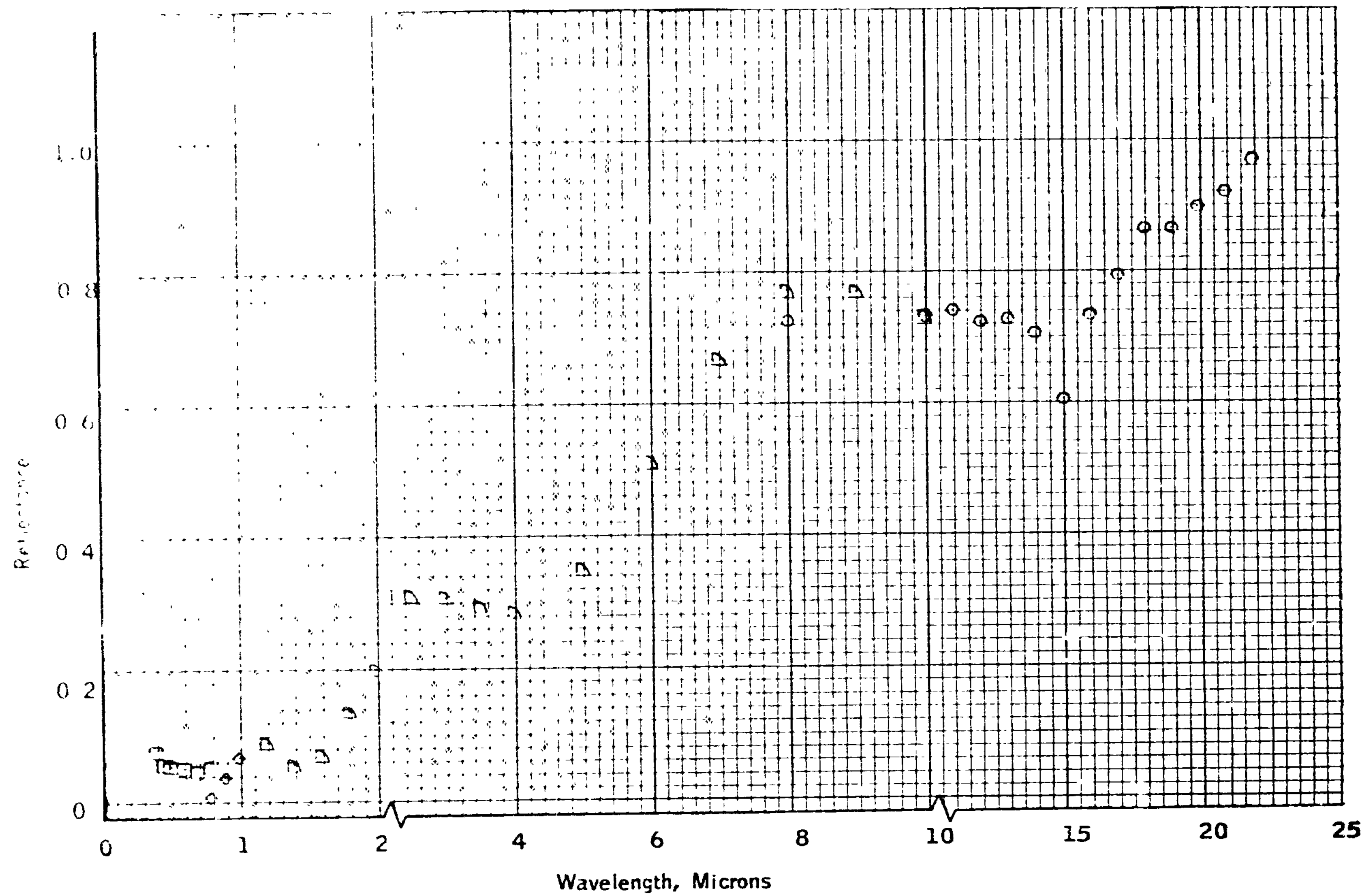


Fig. 173 Normal Spectral Reflectance of Specimen No 177 Temperature RT

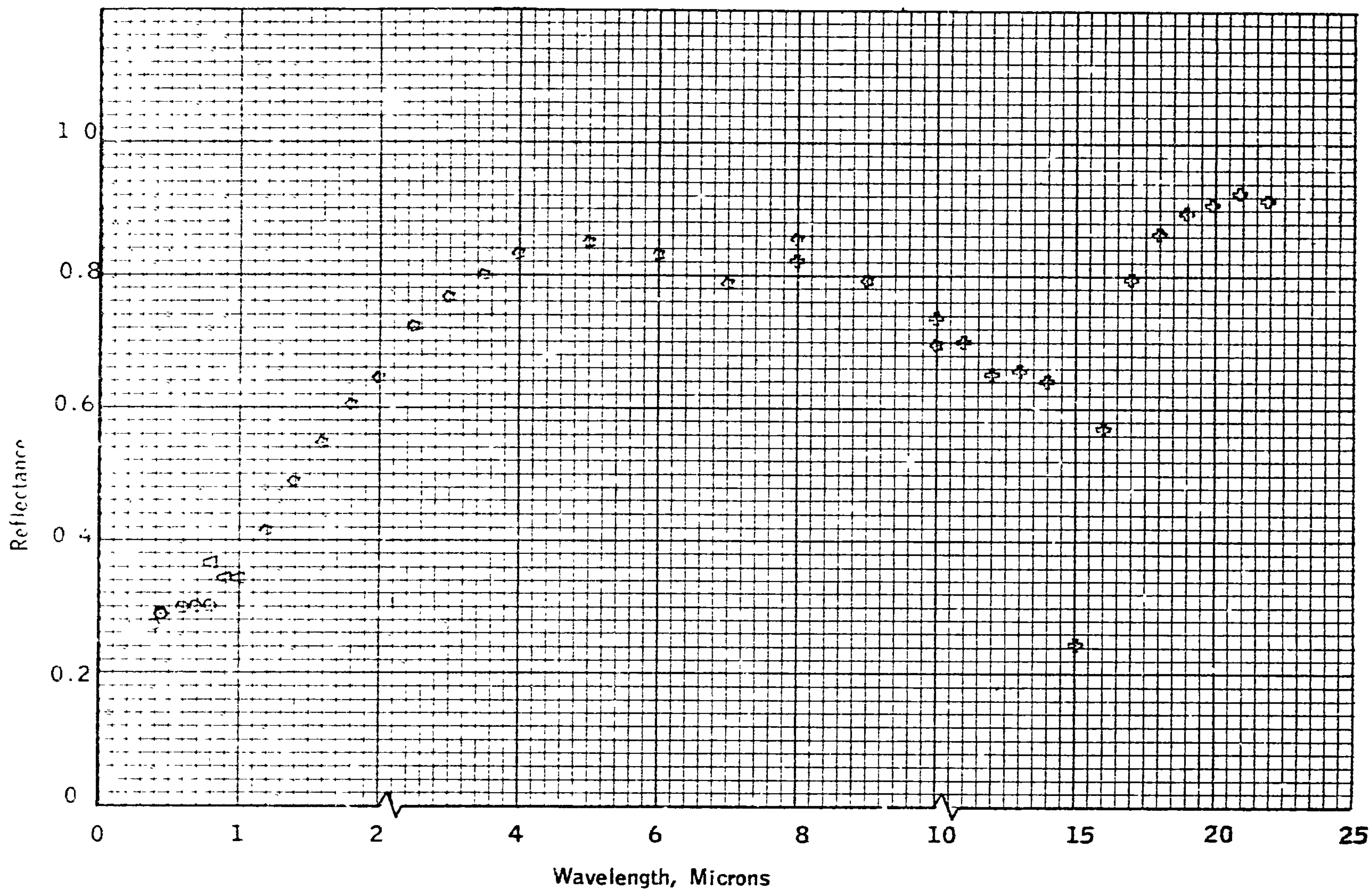


Fig. 174 Normal Spectral Reflectance of Specimen No 177 Temperature RT-HT-1500 F

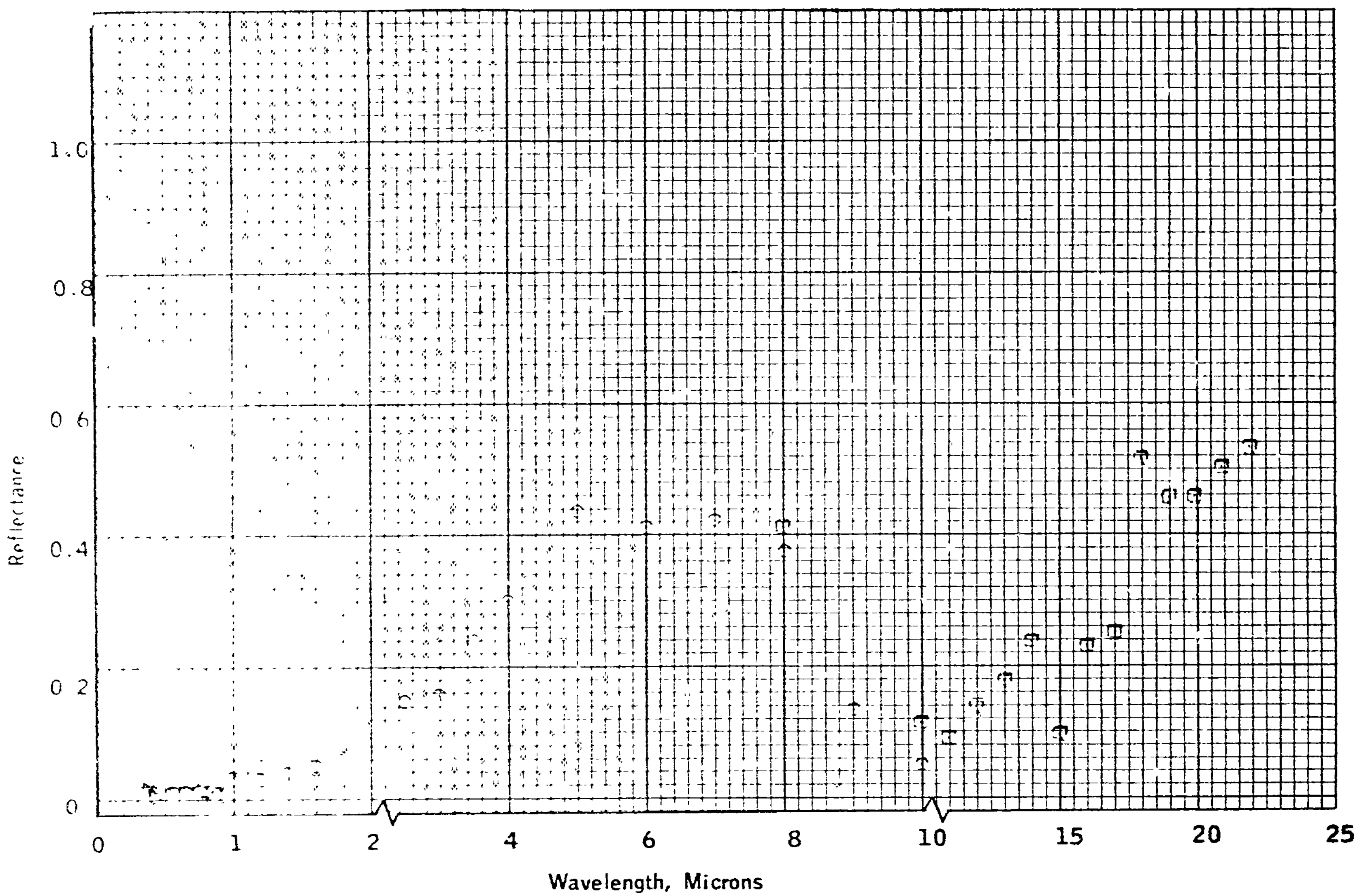


Fig. 175 Normal Spectral Reflectance of Specimen No 167 Temperature RT

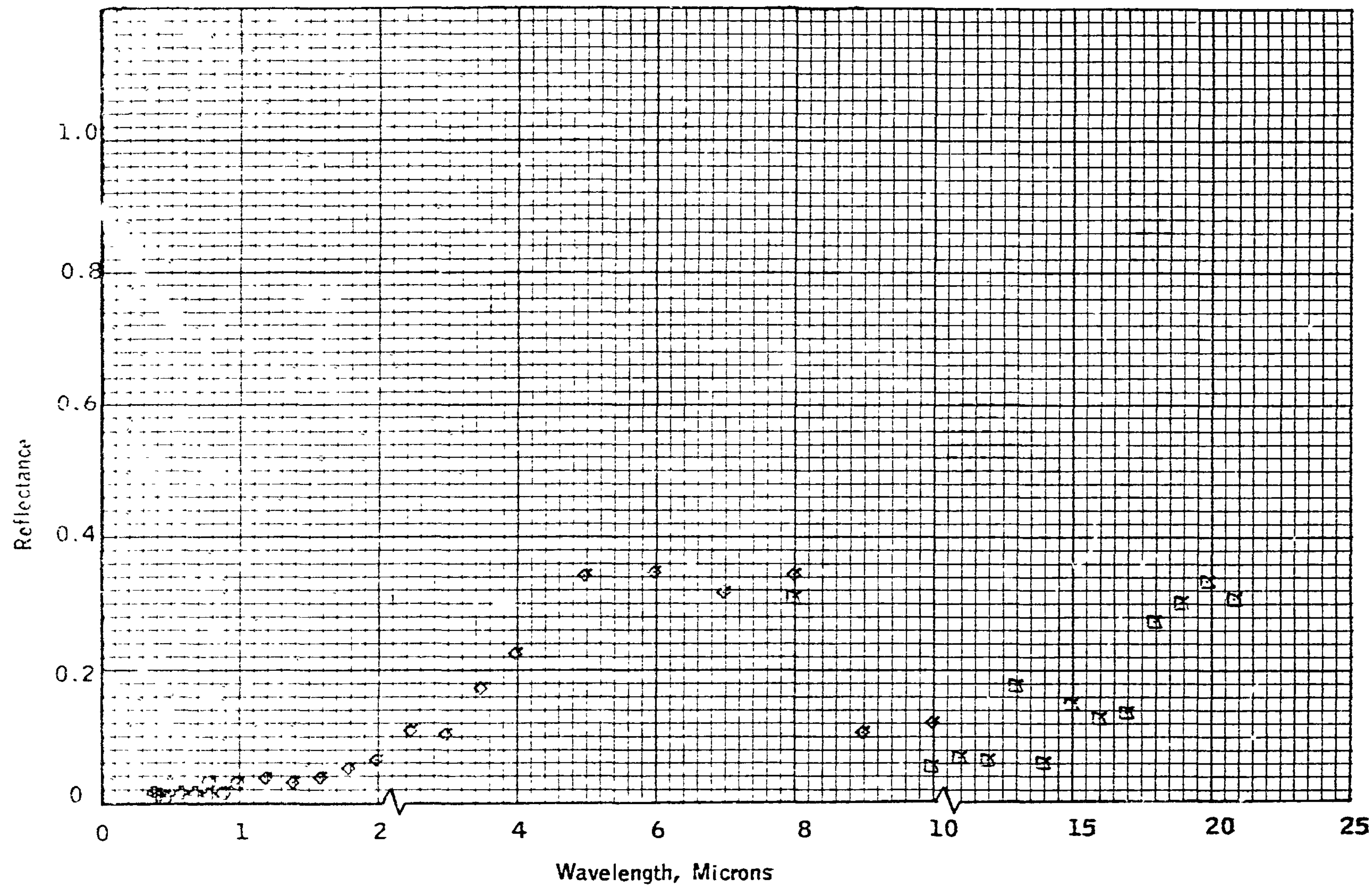


Fig. 176 Normal Spectral Reflectance of Specimen No 174 Temperature RT

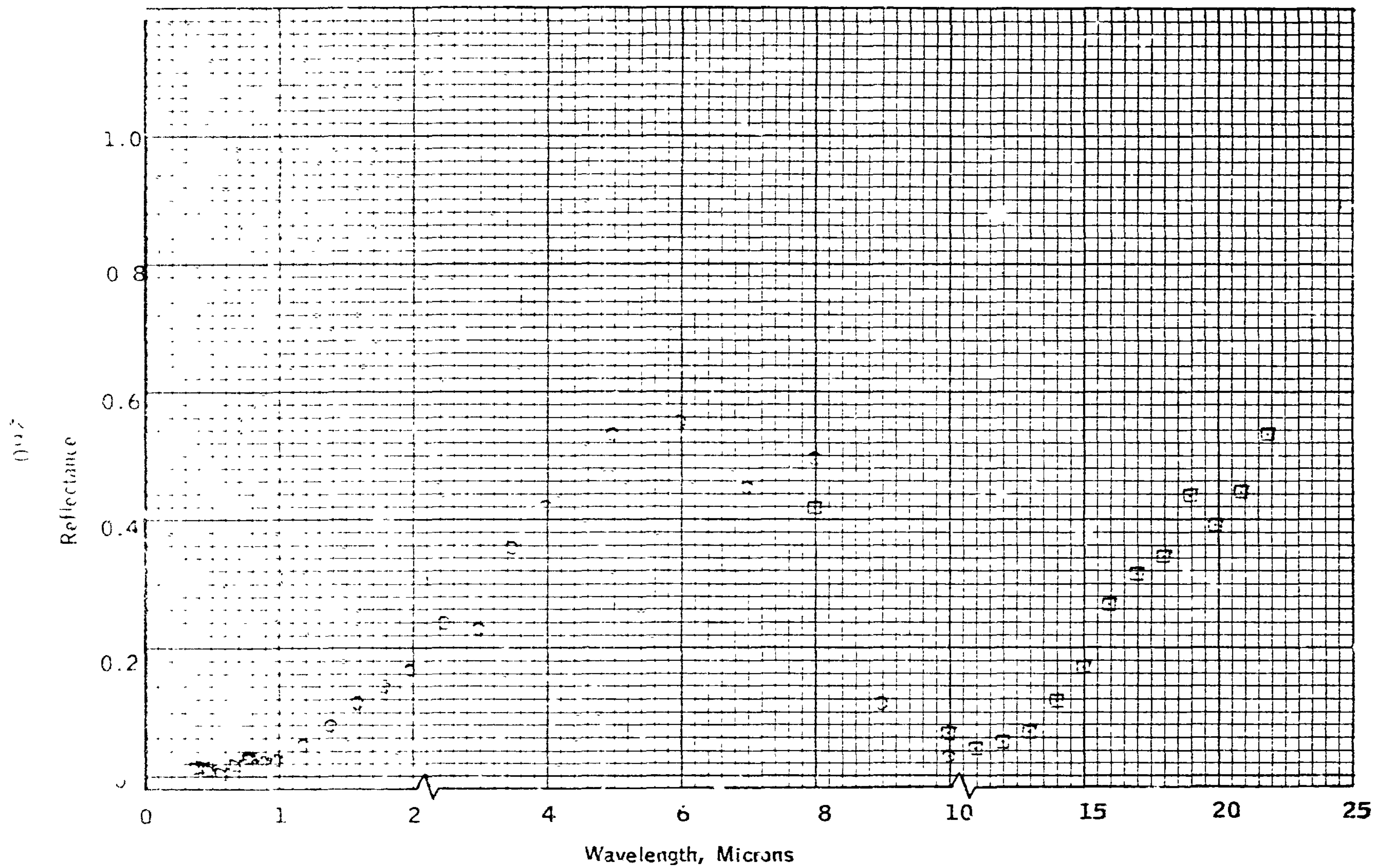


Fig. 177 Normal Spectral Reflectance of Specimen No 176 Temperature RT

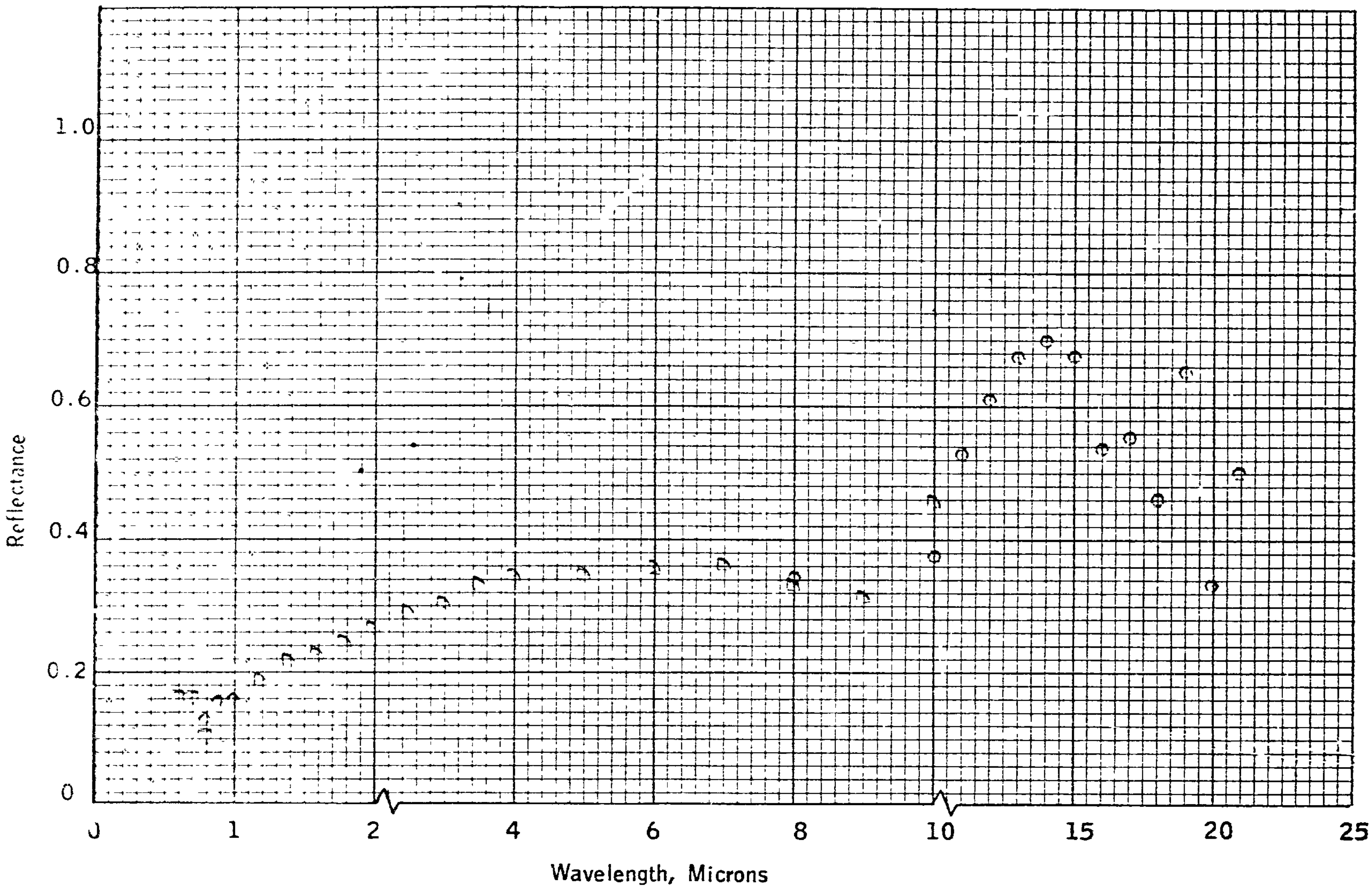


Fig. 178 Normal Spectral Reflc tance of Specimen No 168 Temperature RT

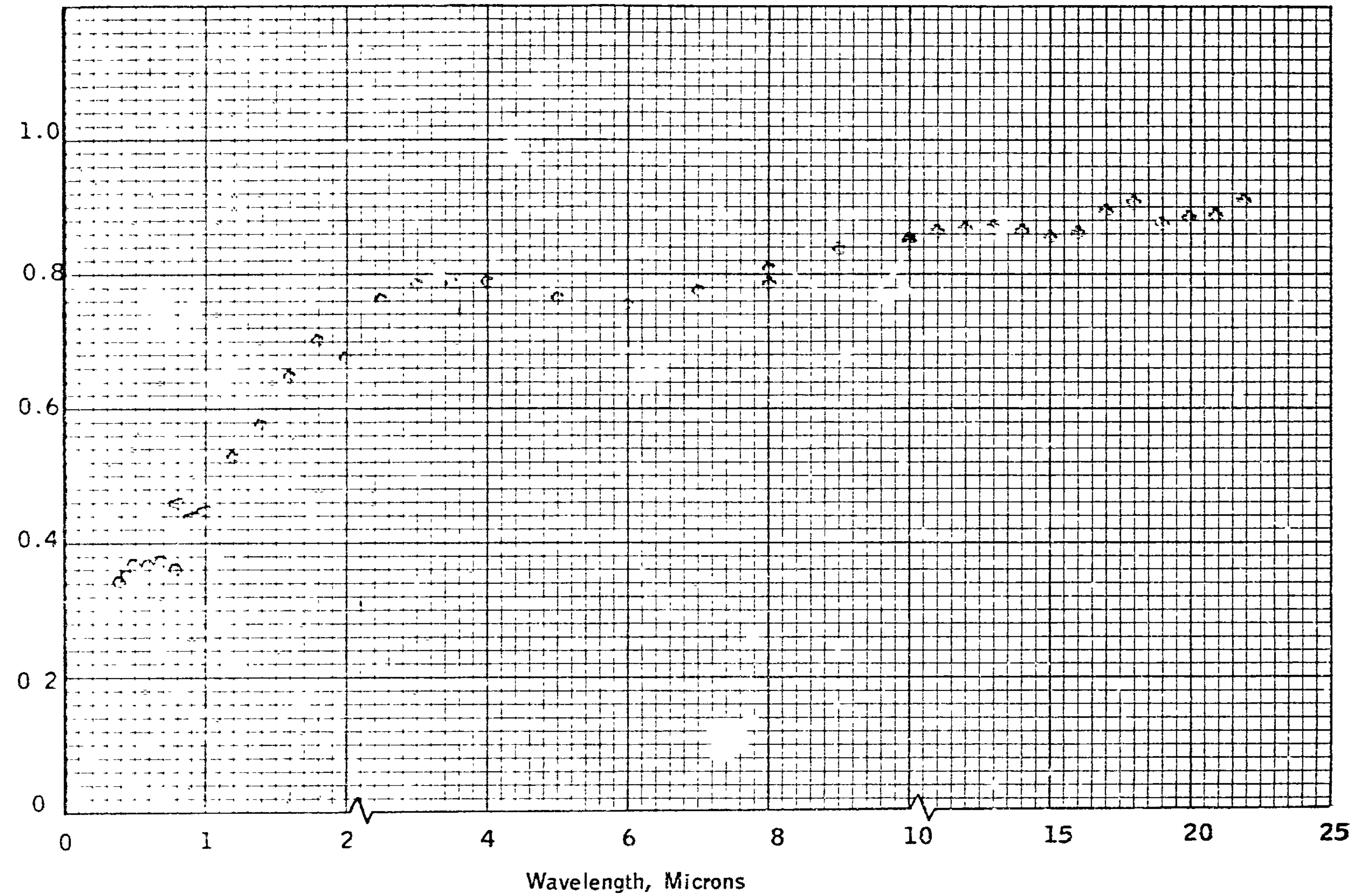


Fig. 179 Normal Spectral Reflectance of Specimen No 170 Temperature RT

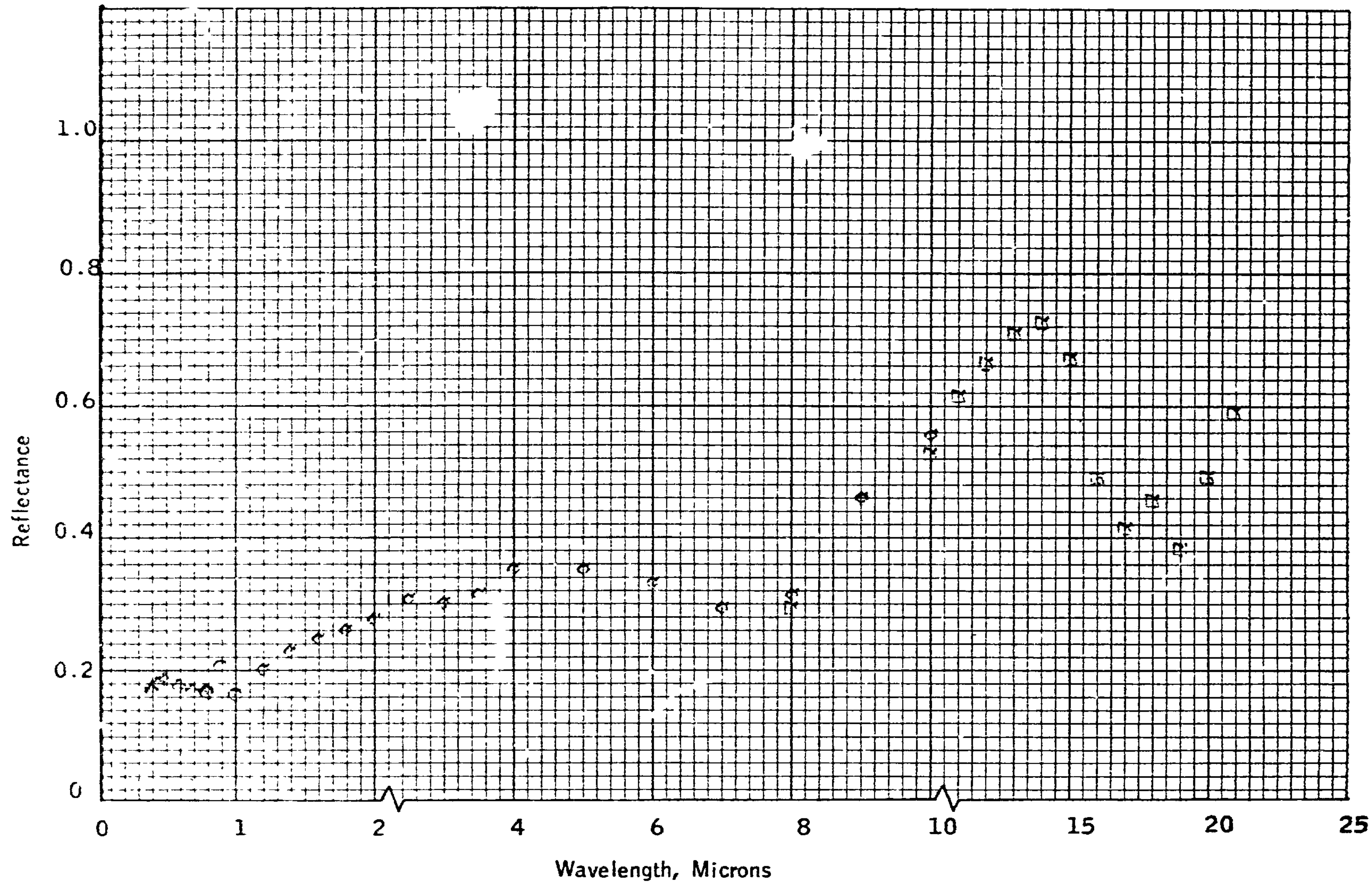


Fig. 180 Normal Spectral Reflectancc of Specimen No 172 Temperature RT

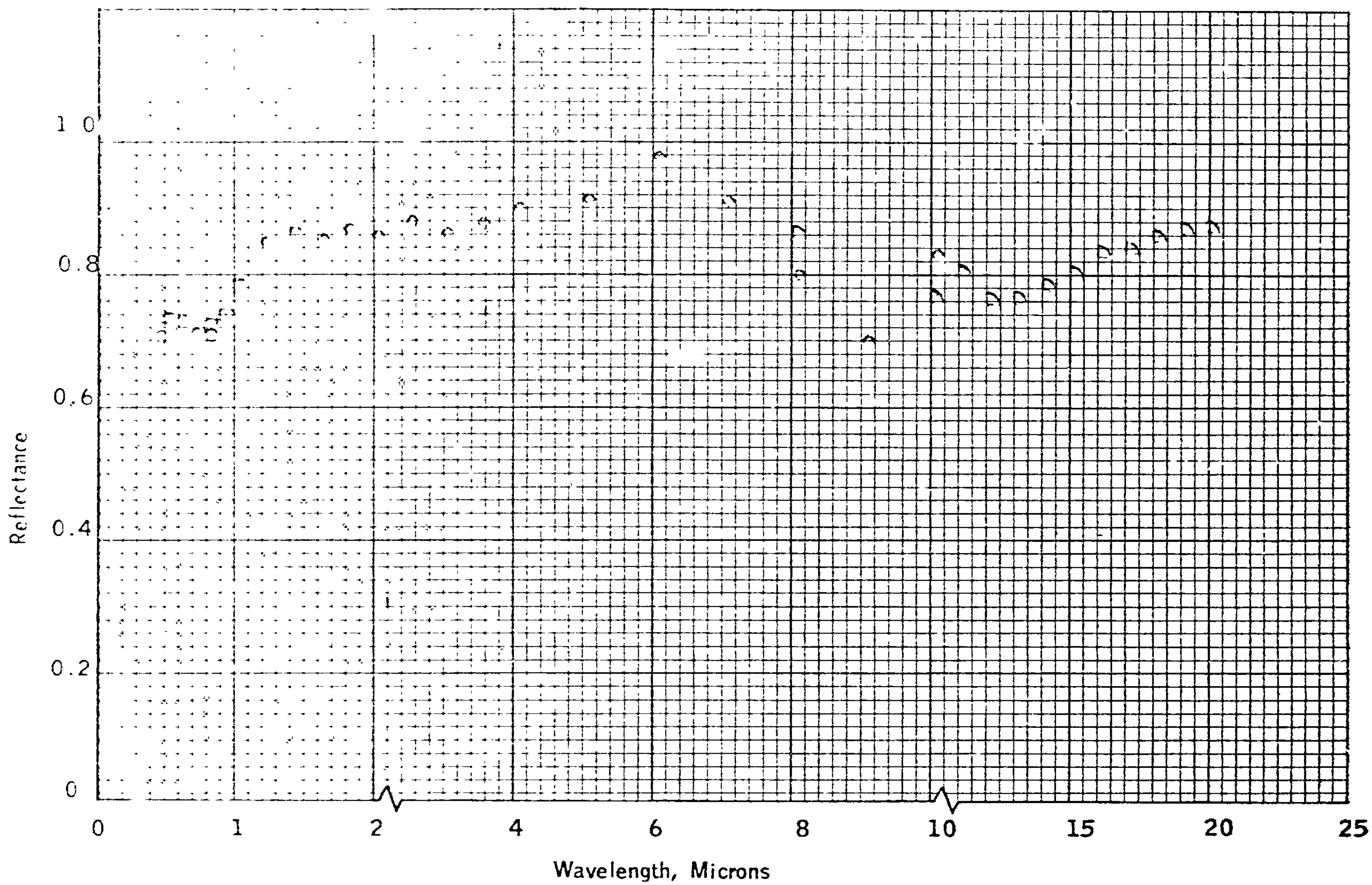


Fig. 181 Normal Spectral Reflectance of Specimen No 18 Temperature RT

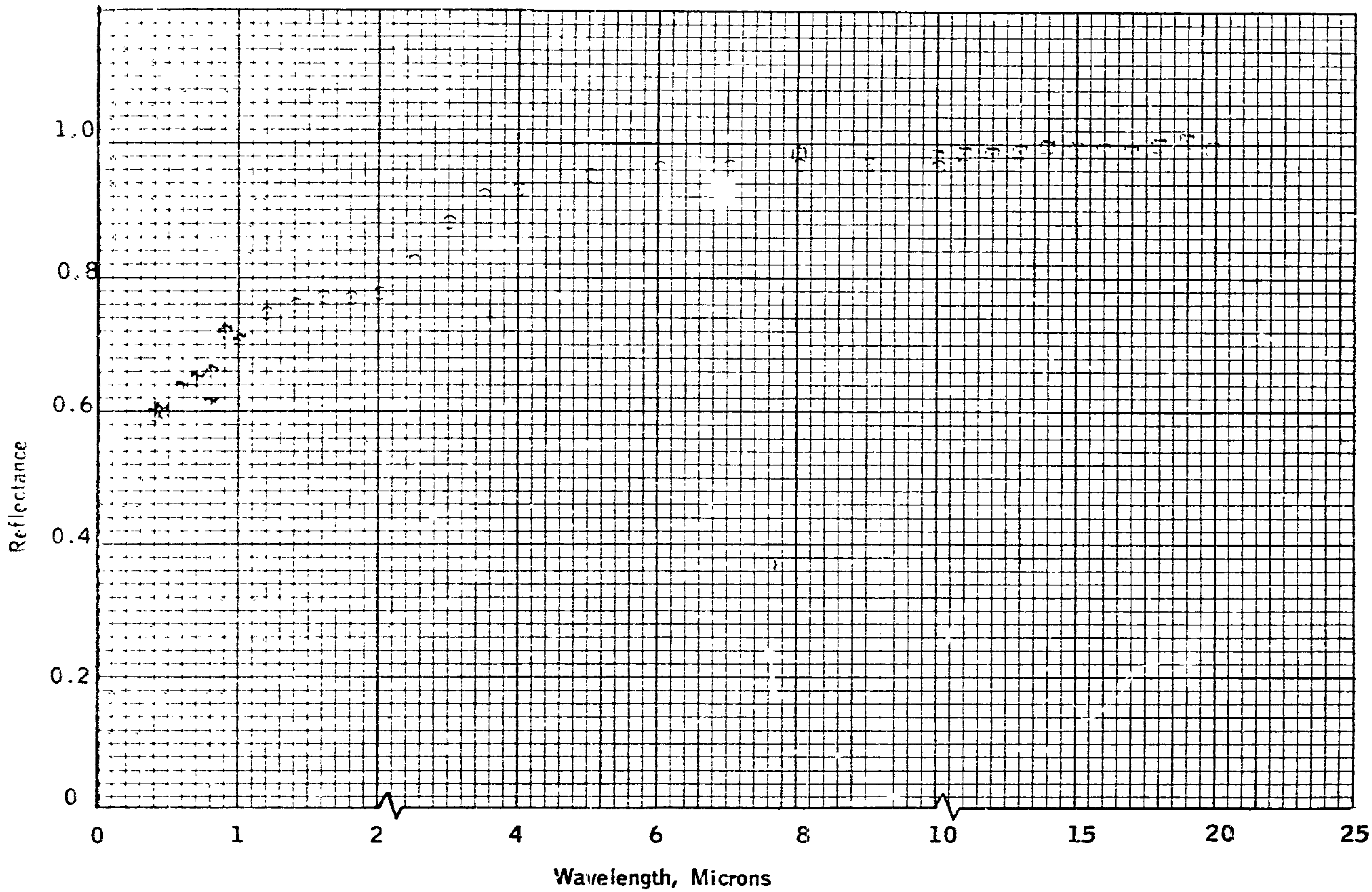


Fig. 182 Normal Spectral Reflectance of Specimen No 156 Temperature RT

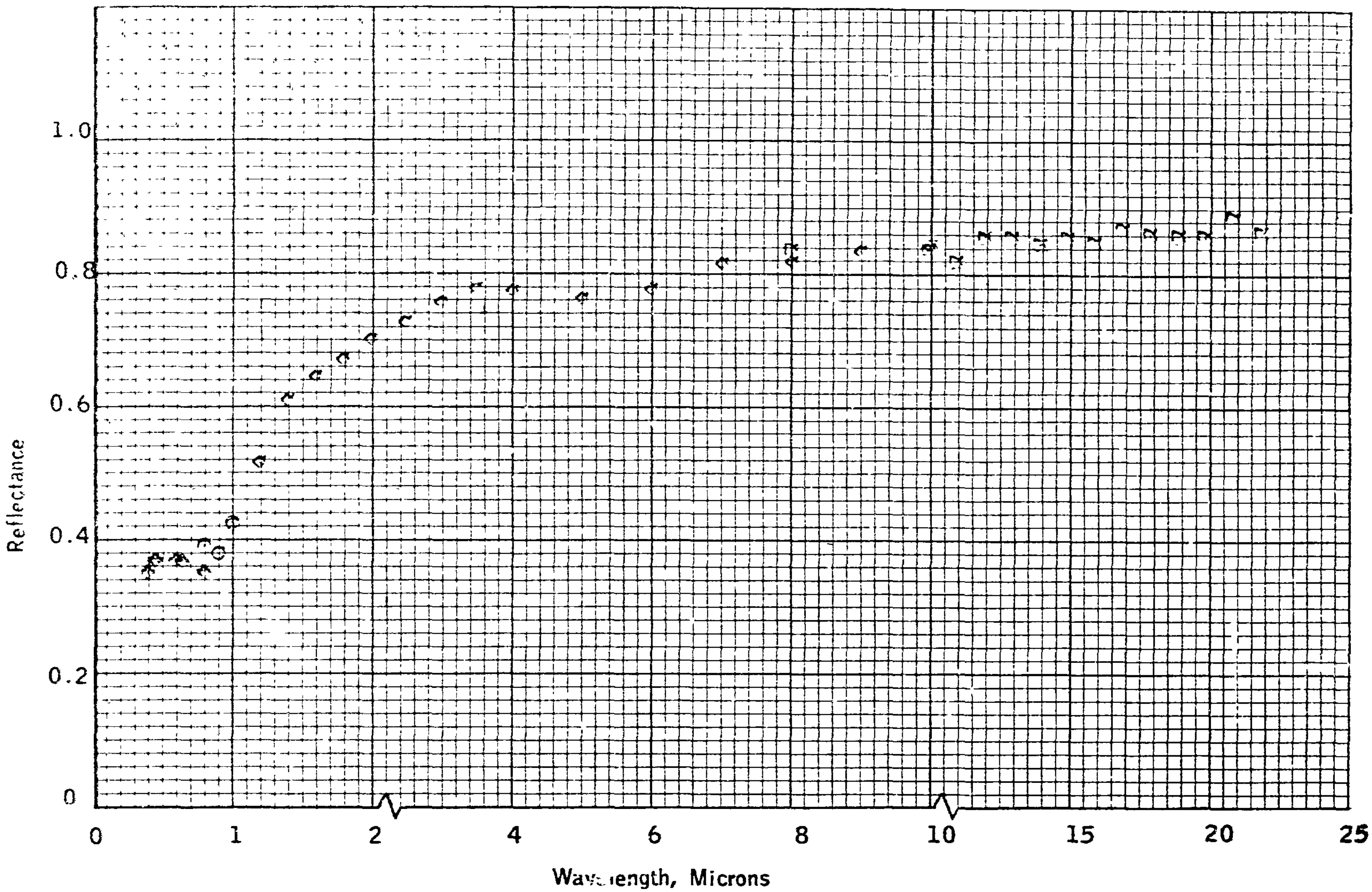


Fig. 183 Normal Spectral Reflectance of Specimen No 171 Temperature RT

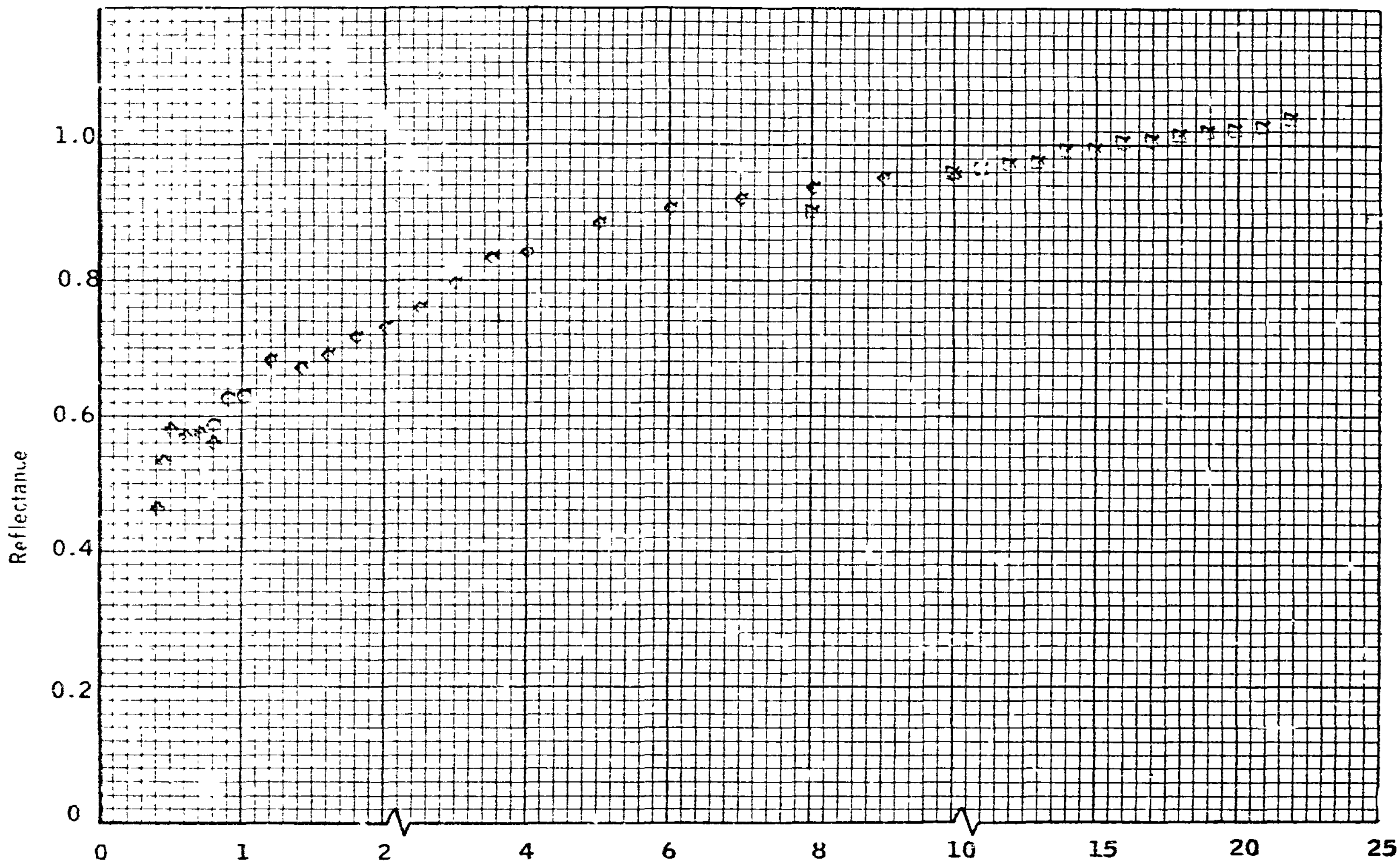


Fig. 184 Normal Spectral Reflectance of Specimen No 4C Temperature RT

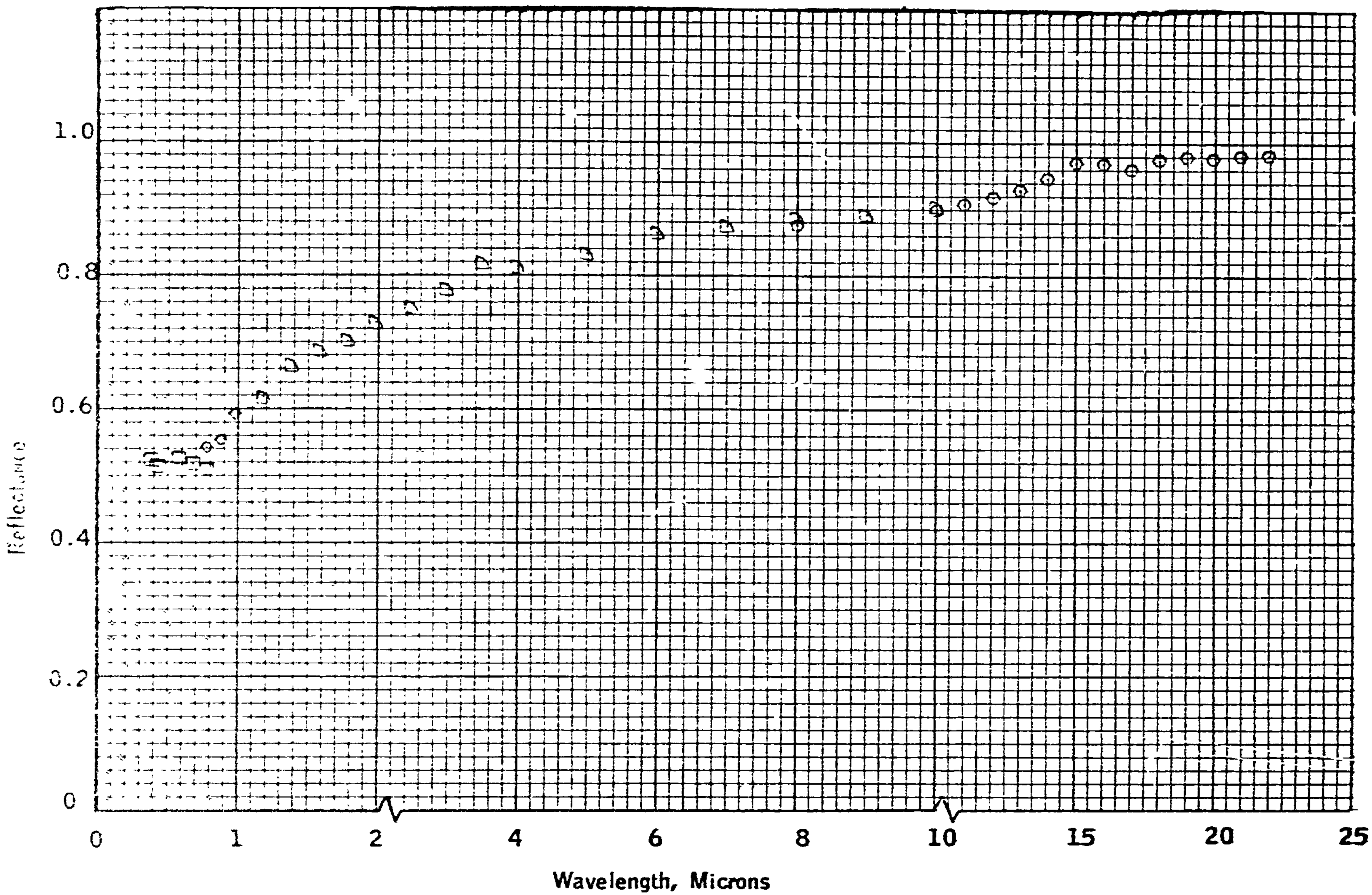


Fig. 186 Normal Spectral Reflectance of Specimen No 202 Temperature RT